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GERO



NOTICE

In its budget speech of February 1992 the federal government announced its decision to disband the Science Council of Canada. This report was in production at the time of the announcement.

Reaching for Tomorrow: Science and Technology Policy in Canada 1991 was conceived to be the first in a series of annual reports in which the Science Council would review and interpret Canada's science and technology policies and activities, thereby contributing to the development of a coherent national science and technology agenda.



Science
Council
of Canada

Conseil des
sciences
du Canada

REACHING FOR TOMORROW

SCIENCE AND
TECHNOLOGY
POLICY
IN CANADA
1991

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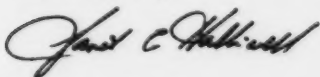
June 1992

The Honourable William C. Winegard, PC, MP
Minister for Science
House of Commons
Ottawa, Ontario

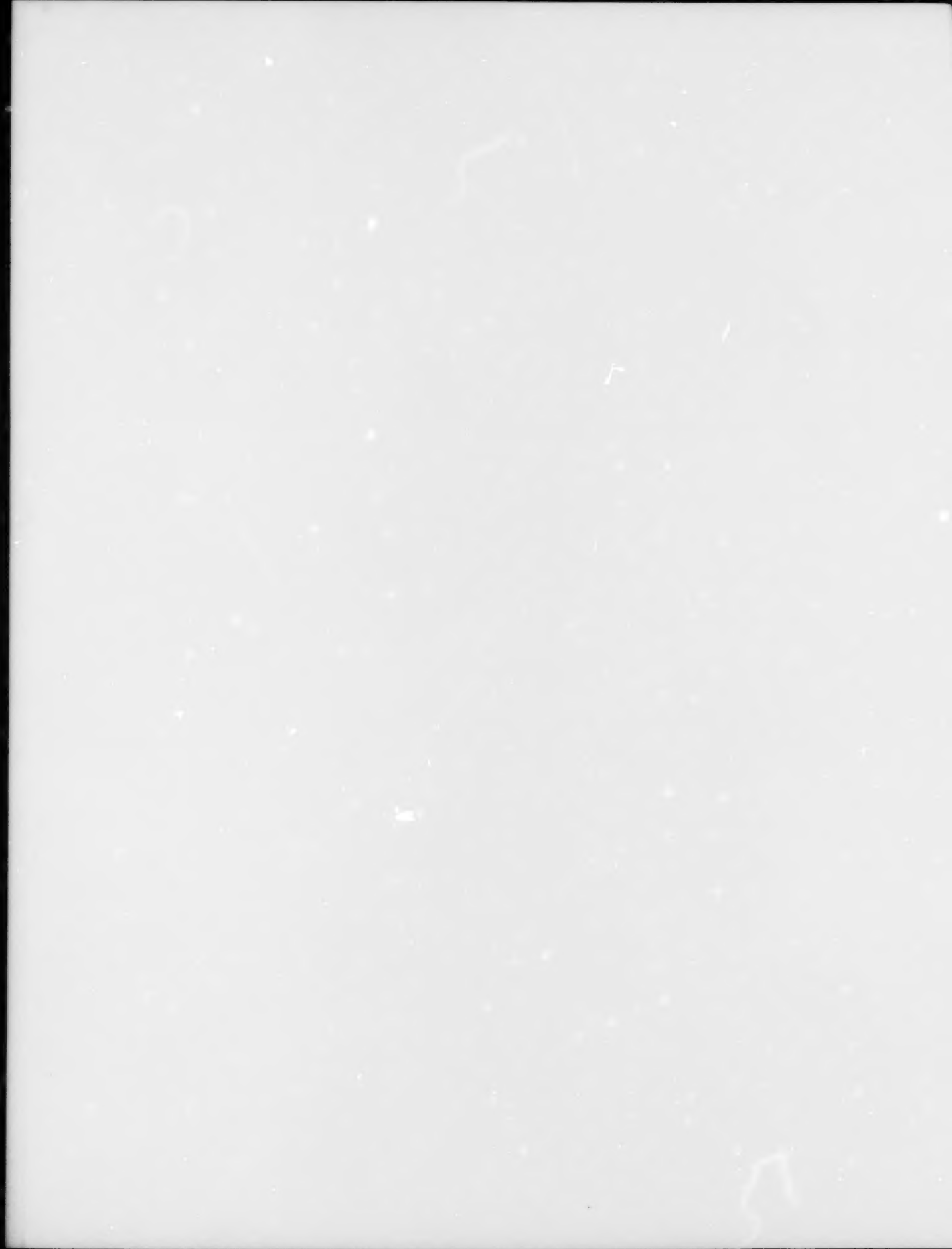
Dear Dr Winegard:

In accordance with Section 13 of the Science Council of Canada Act, I have great pleasure in presenting *Reaching for Tomorrow: Science and Technology Policy in Canada 1991*. This report is the first in a projected series in which the Science Council of Canada will review and interpret the nation's science and technology policies and activities.

Yours sincerely,



Janet E. Halliwell
Chairman
Science Council of Canada



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Preface

Science and technology affect every aspect of our daily lives, and science and technology policy is just as pervasive. Over the last few decades S&T policy has moved from a peripheral to a central position in the decision-making processes of governments, businesses, and educational institutions. As the number of advisory bodies, lobby groups, concerned citizens, and government agencies active in some aspect of science and technology has grown, the quantity of advice has also grown. Once there were only a few voices speaking out on science and technology policy; now there are many. In the sea of voices it has become difficult to keep track of what everyone is saying and to identify currents of agreement. It is equally difficult to keep track of the numerous policies and programs. The observer of the Canadian scene is at once struck by the plethora of initiatives that are being taken. If there are national priorities behind the various initiatives, what are they? There is a great deal going on, but what does it all mean?

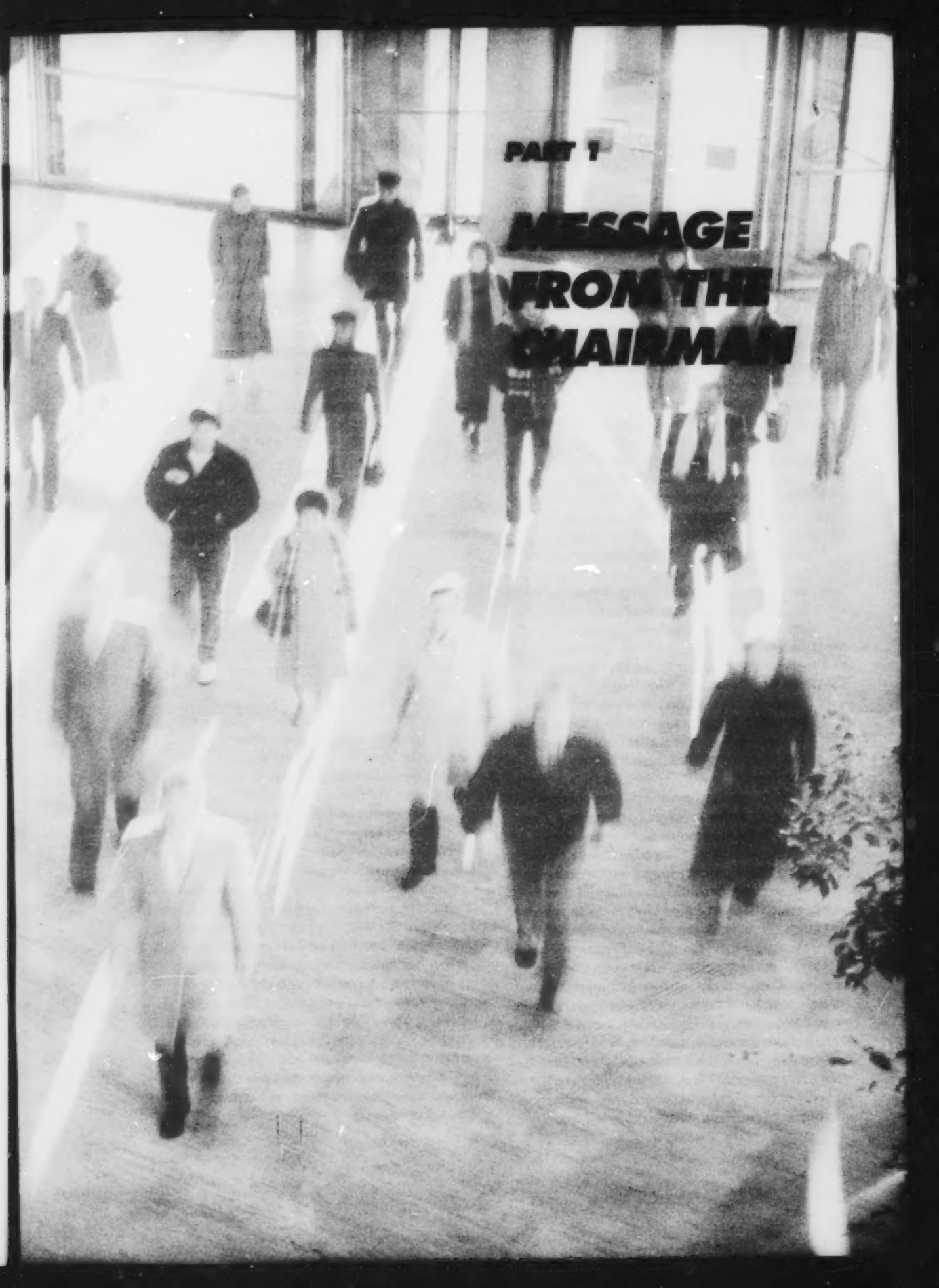
The Science Council of Canada believes it is time to begin a regular review and evaluation of science and technology policies and activities in Canada. The Science Council is uniquely positioned to undertake this task. It operates at arm's length from government, and it is a truly national advisory agency, with a history of conducting multidisciplinary, consultative studies, and of offering sound policy advice to all sectors of society and all levels of government.

The format of *Reaching for Tomorrow: Science and Technology Policy in Canada 1991* is a simple one. Part 1, an essay by Science Council Chairman Janet Halliwell, introduces the broad themes and directions that must be considered in the development of a national science and technology agenda. In a world of constant change, with growing threats to the economy and the environment, Canada needs a durable set of national strategies that combine vision with realism.

Part 2 is a primer on competitiveness and its links to innovation. Despite the ubiquity of the word, competitiveness remains poorly understood. Nevertheless, its importance is undeniable in a year in which bankruptcies soared, whole industries felt threatened, and the issue of unemployment dominated the lives of increasing numbers of Canadians.

The chapters of Part 3 chronicle the main events of 1991 in five areas that could be said to collectively define the scope of science and technology policy. The description of the key events is punctuated by opinions and comments from policy analysts and other participants in the science and technology debate.

This review is the first of its kind for the Science Council but it takes its inspiration from the work of many other groups and organizations. It provides a national perspective that the Council feels is essential to development of a coherent, practical science and technology agenda; it is not a compendium of statistics or statistical analysis. The content and emphasis of future editions of this review will be determined by the reaction of readers to this one. We invite your comments and suggestions.



PART 1

**MESSAGE
FROM THE
CHAIRMAN**

Message from the Chairman

Science and Technology Policy in Canada is designed to provide, on an annual basis, an overview and commentary on the integration of science and technology into the fabric of our society and economy. It is offered to those with a strong belief in the future of Canada and in the same spirit that inspired the creation of the Science Council in 1966.

The essence of that spirit was a concern for the welfare of Canadians, coupled with a perception that science and technology had a profoundly important role to play in maintaining and enhancing the quality of life of Canadians. In a speech to the inaugural meeting of the Science Council on 5 July 1966, then Prime Minister Lester B. Pearson presented his vision of what was really meant by the Council's formal mandate. He conveyed a challenge and an opportunity of immense scope.

He spoke of the need for the governments and the people of Canada to receive advice from an autonomous body on the building of constructive links between science and technology, on the one hand, and economic growth, resource development, health, environment, and the infrastructure of the nation, on the other hand. He challenged the Council to tap the wisdom of the pure and applied natural sciences and the social sciences and humanities. He stressed the importance of applying Canada's scientific talent to global social problems, and of assessing the impact of science and technology on society.

The Science Council of Canada was charged with advising on the shape and dynamics of our national effort in science and technology, the role of that effort in relation to Canada's aspirations, our adequacy in research and its application, the organizational and social structure in which S&T are embedded, and the policies that guide the functioning and deployment of our S&T capacities.

At the time of this inaugural speech, our collective understanding – both in Canada and abroad – of what is now known as science and technology policy was very limited. Little was known about the social organization of research, the links between science, technology, and innovation, the art of research evaluation, the nature and economics of industrial innovation, the new paradigms of environmental economics, the

relationships between technological change and trade, or the underlying causes of technology gaps between nations and differing economic growth rates. Since the mid-1960s researchers and governmental policy analysts worldwide have wrestled with such questions and have succeeded in laying down a rich body of knowledge to effectively inform political choice and private decision making.

What Time Has Wrought

If the charge to Science Council was challenging in 1966, it is even more so now. The world as a whole and Canada itself have changed profoundly in 26 years. Today's geopolitical balance of powers has emerged from a science- and technology-based industrial revolution that is inseparably interwoven with the increased movement of goods, services, capital, and people across national boundaries – the phenomenon of globalization. Those nations that cannot deploy science and technology to compete effectively in global markets stagnate or decline.

To that transformed world, with all of its profound implications for Canada, we must add our more recent recognition that our patterns of production, consumption, and waste generation are leading to irreversible environmental change and a mutual interdependence among all nations of the world. This interlocking of the world economy and the environment has profound implications for the shape of our national and international institutions of governance. This in turn has deep implications for those who practise, use, and fund science and technology.

Canadians are awakening to the realities of competition in an innovation-intensive, globalized economy that is indifferent to our domestic commercial and constitutional concerns. We are observing the challenges to our wealth-creating ability by the aggressive new entrants to the world economy, and recognize that more such entrants will follow. We are recognizing that competitiveness is intensifying, just as we are recognizing the vulnerability of the global ecosystem. We know we must respond to these multiple challenges if we are to retain those aspects of Canadian life we value.

How do we achieve this? And what is the role of science and technology? There is no "silver bullet" answer. We are dealing with issues that are infinitely more complex than they were at the time of Science Council's founding. Institutions and policies that served Canadians well in the past are unable to cope with the nature and pace of the changes. Some of the knowledge base needed to renovate these institutions and policies lies in the S&T policy literature, but there are still many questions to old and emerging problems yet to be answered. However, one thing is certain: we have the essence of the solution in our people. The health of our economy and environment depends more and more on how well we nurture and benefit from the intellectual strength of Canadians – on the way we use our skills and intellectual resources in a flexible and continuously evolving economy.

The institutions and the policies that guide the development and deployment of our intellectual resources are the stuff of a national science and technology agenda. In the following pages, I hope to provide a broad vision of today's international and domestic S&T climate with a particular focus on competitiveness (the theme of this year's report). I then suggest directions for a national S&T agenda that will enhance the capacity of Canadians to develop and prosper – the Science Council's contemporary response to Pearson's original challenge to the Council.

International Dynamics

In recent years the world competitive environment has been increasingly characterized by the efforts of firms, often aided by governments, to systematically harness science and technology to gain advantage over others in national and international markets. New technologies (e.g., microelectronics and advanced materials) have transformed existing products and generated entirely new ones – witness the VCR, the fax machine, and compact discs. An even more fundamental revolution has been the radical change in production technologies and organization. The changes do not stop here, however. The very nature of innovation is changing – to accommodate more and more a complex interplay of technological, human, and organizational factors – in a way that gives functional, qualitative, and temporal advantage over competitors.

These changes penetrate much deeper than the high technology industry. Resource-based industries are using new technologies to transform production processes and products. Service industries, businesses of all sizes, and the pursuit of research itself are being radically transformed by the introduction of new tools – especially those derived from the information technologies. Everyone is affected by technological change.

Part 2 of this report, "Competing through Innovation," details the interplay of science, technology, innovation, and competitiveness, and outlines new concepts of management and business that are revolutionizing the global process of wealth generation. It argues that an innovation culture is critical to the future competitiveness of Canada. It also stresses that in developing this innovation culture we must recognize the changing nature and pace of innovation and reassert the central role of our human resources – people, and the skills and flexibility they bring to the workplace.

As described in the "Infrastructures" chapter of this report, there is global recognition of the important role that national S&T systems play in underpinning this innovation culture. Necessary, although not sufficient, conditions for an innovation culture are strong infrastructures for science (public and para-public research facilities, systems producing highly skilled people, networks among researchers, and funding systems that provide selection and support) and strong infrastructures for technology (the support systems and linkages that foster the development of technology and its dissemination and transfer by and to the private sector). It is the effective union of these science and technology infrastructures with managerial and organizational innovation that provides comparative advantage for a nation. An innovation culture cannot flourish in isolation, however; governments shape national S&T systems according to their philosophies of the appropriate balance between public intervention and market forces and the values of their citizens.

Given decreasing national barriers to trade, global competition is driven by two fundamental forces – the competitive position of a firm itself and the national ground rules established by its domestic market system. From one country to another these domestic market systems vary widely and often are influenced as much by historical and cultural factors as by economic conditions. Because these systems can have

profound impacts on the science and technology infrastructures of a nation – on the environment for innovation and the ability to compete – they are beginning to capture some of the international attention that was previously concentrated on more conventional trade barriers. Whether domestic policies should or can be harmonized has now become a focus of considerable international debate.

There is now another profound paradigm shift for industrialized nations: the realization that human activities affect the environment in a pervasive and long-term manner. Human activities have now become so far-reaching in their effects that many of them are of the same scale as fundamental natural processes. A consequent demand by the public for environmental sustainability has taken shape much more quickly than the ability of our political, scientific, and economic systems to respond. In essence, we are moving to a worldwide recognition that there are limits to unfettered economic growth. But no nation has yet effectively grasped the full measure of changes that need to be made.

Our understanding of the various dimensions of sustainable development is much deeper now than some 30 years ago. Many believe, however, that while there are limits to unfettered growth there are still enormous opportunities for economic development and that the paradigm of sustainability can be reconciled with national competitiveness, often through sophistication of products and processes. Whatever one believes, it is clear that our ideas about the production of goods and services are shifting, with the focus turning to adding value, not physical resources – to doing more with less.

The new paradigm of sustainability is a call for change; it involves management vision and industrial procedures that conserve resources, minimize waste and environmental impact, and promote ecosystem resilience and sustained production – processes that require the extensive but judicious use of science and technology.

The goal of sustainable development reminds us that it is the pursuit of a higher quality of life, rather than a brute struggle for survival, that has been at the heart of much scientific advance. There is strong societal support for science and technology that enhance life and welfare. There is also wide societal support for intellectual activity at the frontiers of science and engineering – the challenges that enrich and satisfy the human soul. This is an essential part of the science base. There

is, however, deep public scepticism about some of the supposed fruits of science and technology, especially if they are seen as leading to deterioration of the environment or unrestrained commercialism. Public support is essential for the health of the scientific enterprise and the effectiveness of its application. To this end, the cultural, social, and human dimensions of science and technology must be kept in mind if we are to have a balanced integration of S&T into the economy and society.

Worldwide, the emergence of these new issues has revealed inadequacies in human understanding and has challenged existing institutions, attitudes, and policies. Canada is no exception.

Canadian Dilemmas

Canada is a relatively prosperous nation with an enviable standard of living and a tradition of outstanding contribution to international diplomacy and development. We now, however, find ourselves in a state of anxiety, and are losing, it seems, a great deal of our economic advantage. Our relative standard of living is starting to suffer accordingly. Some of our social and political institutions have not performed as we had hoped and we are confronted by environmental realities that we failed to anticipate. We appear to be a society searching for a sense of direction and commitment and apparently resigned to the reconstruction of some institutions and major aspects of public policy. After a great deal of analysis, however, a coherent picture of the problems Canada faces is emerging, and thus the general direction of the solutions.

In the chapter of this report dealing with recent actions to stimulate industrial innovation, we review how Canada is currently dealing with the many problems facing our economy. There are various efforts to improve our ability to use innovation and to identify and apply new technologies in a timely way. Unfortunately, most Canadian managers have yet to demonstrate their understanding and appreciation of the new business environment in the global context.

The key message is that knowledge, training, skills, and hard work must be coupled with private sector vision and capital. To lack skills or education is to be at risk. Even more, not to use existing skills or education is to throw away a competitive advantage. Recognition of the role of "intellectual capital" in competitive success is forcing countries to take a hard look at the effectiveness of public policy in developing intellectual resources.

Most Canadians support the concept of lifelong learning and skills development. Some, however, question the goal of producing more scientists, engineers, and technologists in the face of current unemployment numbers. Yet such an attitude may simply ensure Canada's demise as a competitive nation.

For we have in Canada a dissonance in our systems of research and of development. Our university system – for all its shortcomings – bears the characteristics of a system appropriate to a modern industrial economy. But the economy itself – at least in its use of “knowledge inputs,” its R&D dimension, especially in the private sector – seems to behave like that of a semi-industrial state. R&D investment by business is low and skewed to incremental technological advance rather than innovation. To add to this dissonance or mismatch, our attitudes, policies, and programs in the vital area of technical training and apprenticeship – as well as in corporate workforce training and adult education generally – are of the kind that you might expect to find in a less-developed country.

Pushing on the end of a rope is not enough; the “demand” for human resources must improve. The solution is not to renounce or to diminish our commitment to scientific and technological education or research. Rather Canada must create an environment in which discovery, invention, and innovation flourish and are fostered by an active and productive private sector that stimulates demand for the best. We must educate our citizenry more effectively. We can then use our intellectual resources to sustain a quality of life that supports Canadian values and to become as smart, or smarter, than our competitors in applying creative ideas to both economic activity and social and environmental structures and services.

The societal aspects cannot be ignored either. Until the public comes to terms with the fact that technology can be deployed in a manner consistent with the goals of social justice and environmental sustainability, we will continue to flounder. This raises the vital issue of the quality and suitability of the education that all Canadians, not just the practitioners of S&T, receive. If Canadians are to make effective judgements on the use of S&T, our educational system must make mathematics, science, and technical subjects more accessible to all. Our postsecondary education system must continue to evolve, providing both areas of concentration and multidisciplinary

education to all students. In the workplace, researchers and managers are increasingly faced with difficult societal and institutional demands while pursuing research and development. They find that training in foreign languages, history, and financial training would be an asset. We may, in fact, have to face significant institutional change to accommodate better training in business practice, to say nothing of continuous learning, mass public education, and high-level specialization.

Our educational system should provide for two streams of students – educating and training, on the one hand for the broader purposes of society and on the other for the development of particular intellectual skills, including research and development capacity. We cannot have one without the other if we hope to succeed either socially or economically. Achieving both, however, within the bounds of fiscal realism and continued movement to mass education may require a cultural and institutional change in higher education.

Unless we are eventually to sell our labour – be it intellectual or physical – for a mere pittance, and that only to survive, we must recognize that our collective wellbeing in the future will depend on Canadians possessing high levels of training and education. It is a deep and continuing involvement in learning, but not necessarily in conventional or narrow ways, that we are talking about when we champion the cause of “lifelong education” or the “learning culture.” The quality of the social culture in which R&D activities are embedded is at least as important as R&D itself.

Science and technology also underpin our relationship with the environment. As northerners with a vast landmass and a harsh and unforgiving climate and terrain, Canadians necessarily have devoted much of their physical, intellectual, and financial resources to forging an accommodation between human aspirations and the physical environment. This dominant influence of the land and sea has in turn greatly affected the development path of Canadian science, technology, and business. We have enormous research strength in earth and environmental sciences and in civil, geotechnical, and ocean engineering, and our economy is dominated by the communications and resource industries. Over time other areas of strength have emerged, adding depth and diversity to the intellectual and technological fabric of Canada. Some of these are highlighted in the “New Frontiers” chapter of this report.

Some see the geographically and historically driven characteristics of Canadian competitiveness as being out of balance with the contemporary realities of technology-driven innovation, knowledge-intensive trade, and global competition. This is simplistic. These characteristics should, rather, be seen as providing Canada with a special opportunity. We can build on this special set of competencies to decrease the throughput of physical resources associated with economic activity by focusing on adding value, reducing waste, and controlling consumption patterns – the actions necessary if we are to move towards sustainable economic development. Our economy is an expanding system operating on a finite and non-growing planet. The limits to growth are increasingly determined more by consumption patterns than by resource deficiency. If we are to manage these patterns with public policy, we need a new understanding of the links between human activities and the biogeosphere and we need new energy and environmentally benign technologies. We also need new approaches to managing the life cycle of our resources and the products derived from them, as well as new approaches to our relationships with developing countries.

But, while new understanding is needed, institutional and policy change must proceed. Decision makers must make judgements in the face of uncertainty and ambiguity. We need the confidence to deal wisely with that ambiguity.

A National Response

In response to the external and domestic challenges, Canada has not stood still. The country has developed institutions, decision-making systems, and policies that bear on every sector of the economy and numerous aspects of our social fabric. Science and technology are increasingly recognized as vital elements in these initiatives.

But we know there are still serious deficiencies, simply by looking at the state of Canada's economy. One must ask if we can, as a nation, produce a set of policies and action plans that blend vision with realism. Perhaps we have focused too much on searching for that elusive single silver bullet. If so, it is timely to remember the old adage: "To every human problem there is a solution that is simple, neat, and wrong."

There must be no oversimplification of the dynamics of innovation and the changing nature of competitiveness. A better understanding of

the nature of science and technology and their interrelated support systems is a key element in our ability to make decisions that will direct our path towards prosperity, but it is not the only key. Strategic vision and management capacity are even more important.

There is, however, a need for clear directions for action. The Science Council has a continuing role – as do many others – in analysing S&T policy options and catalysing that action.

In Canada, the Science Council has been joined in its advisory capacity by the National Advisory Board on Science and Technology, S&T advisory bodies in each of the provinces, and a Council of Science and Technology Ministers comprising representatives of federal, provincial, and territorial governments. The voices of trade associations, technical and scientific societies, and other professional groups are also being heard. This report monitors these voices and tracks the responses of public policy.

The general shape of the S&T agenda for Canada is evident. If we are to have a long-term capacity for economic development, a short-term approach won't do. We need confidence, determination, and a durable set of national strategies and policies.

Throughout the developed world, science and technology policy has moved to the centre of the public policy stage. Effective management of science-based innovation is now broadly understood to be indigenous to the economic system, and the basis of the competitive success of increasing numbers of firms or industries. This, in turn, places new expectations and demands on the science infrastructure and future practitioners of S&T.

The phenomenon of globalization is having a profound impact on the way in which nations handle their S&T systems. Globalization contains three distinct dimensions:

- the increasing movement of goods, services, capital, ideas, and people across national borders;
- the rise of global corporations and supranational political or scientific entities;
- the growing number of problems or situations that inherently involve more than one country and that cannot be effectively addressed by domestic actions alone (e.g., the environment, world population trends, and certain health and welfare issues).

With this context in mind, it is urgent that we work to improve our capacity to acquire, generate, absorb, and apply science and technology. Priorities are:

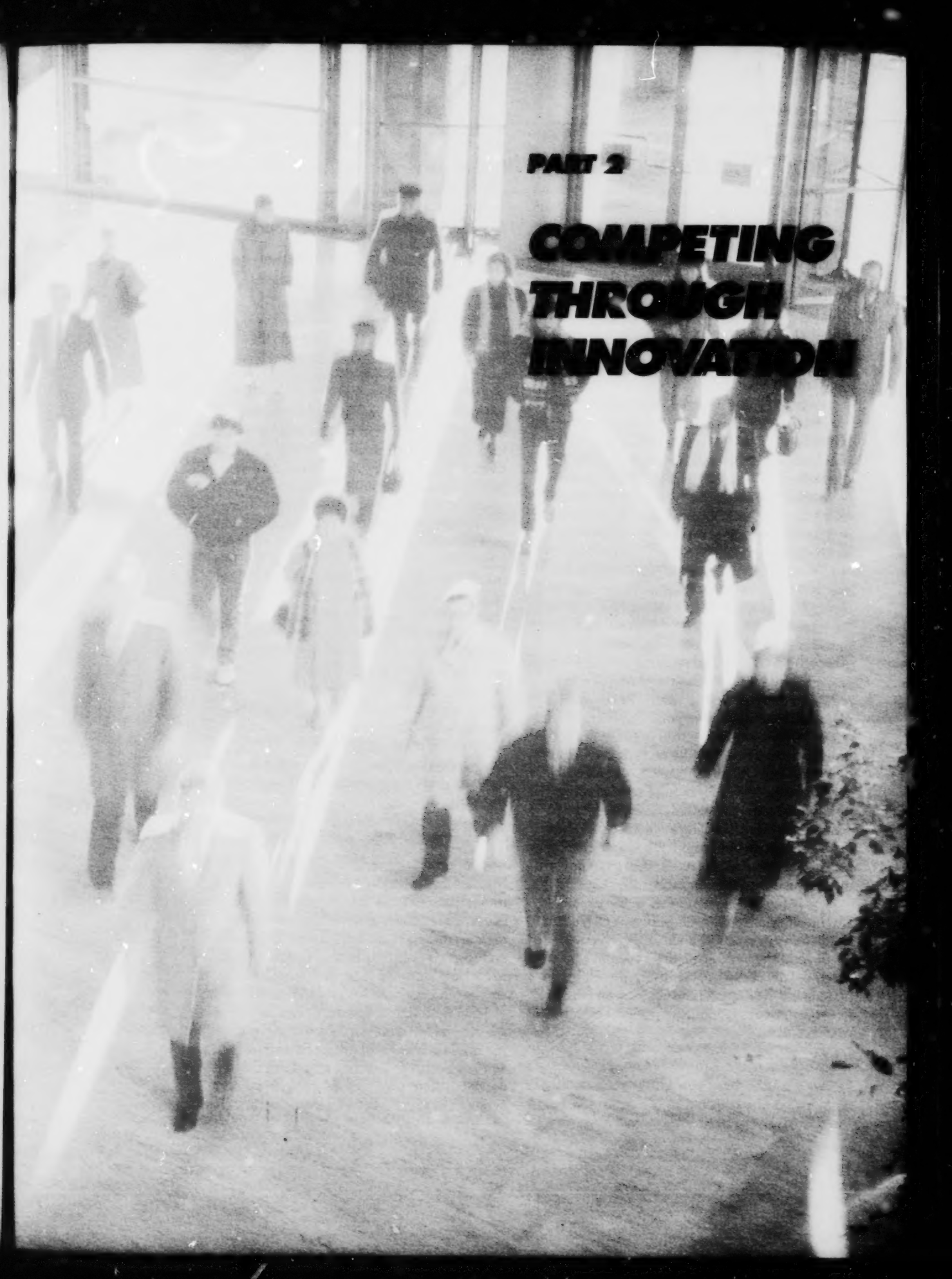
- To develop a consensus on how we could better use S&T to address the major economic, environmental, and social issues of today and tomorrow. This will require an unprecedented level of cooperation among major players in society and a sharing of public and private resources and talents.
- To strengthen the technology infrastructure (the support systems and linkages that foster the development and dissemination of technology and its transfer by and to the private sector).
- To strengthen the science infrastructure (the collection of public and para-public research facilities, the systems producing highly skilled people, networks among researchers and funding systems), particularly to accommodate the effects of globalization and the increased demands placed on the science infrastructure by society.
- To enhance our systems of learning, by refining the system of formal education (at all levels) and improving continuous training and skills upgrading.

Long-term vision is required to adapt to the new paradigms of competitiveness, globalization, and sustainability. Inevitably, the major burden of responsibility must fall on the private sector – the source of our wealth-generating capacity. What is most in demand here and elsewhere is *evolutionary* adaptability and responsiveness. The pace of change is itself changing. Canada must embrace and even lead that change for its own wellbeing.

In Conclusion

Lester Pearson had remarkable vision in 1966. He foresaw the linking of science, technology, and society and the need to develop and utilize science and technology to enhance the quality of life. There was an intrinsic validity in his challenge to the Science Council that has stood the test of time. We are facing, nationally and internationally, a rate of change unparalleled in history, with S&T being both a driver of change and a means of coping with change. In an evolving world, attitudes, institutions, and policies must evolve.

At the same time we must seek new frameworks for understanding relationships and linkages, such as the link between science and competitiveness, and new insights into how public policy can accommodate the changing face of science and technology. Most important of all, however, is to enhance our capacity for long-term economic, environmental, and social security in a world of constant change – a capacity that can be realized only through improved wealth generation, which, in turn, requires better nurturing of our human resources. Canada has fared well to date, but we are on a threshold. Our ability to accommodate rapid change is the S&T challenge and the human challenge of the decade.



PART 2

**COMPETING
THROUGH
INNOVATION**

Competing through Innovation

A Critical but Inadequate Debate

It has been called a cliché, "the C word," and an evangelical pursuit.¹ It has engaged the media, business, and most citizens. It has been the subject of analysis, polemic, rhetoric, and extensive consultation by governments at every level. And yet, the issue of competitiveness – which lies at the very core of our long-term well-being – remains unresolved.

What is at stake is nothing less than the livelihoods of our children, the levels of education and health care we will be able to afford, and the kind of environment that will surround us. How competitive we are will depend quite simply on the intellectual abilities and skills of our people, on the kinds of industries we attract and develop, and on the strength of our policies and policy mechanisms.

Unfortunately, the debate about competitiveness has to date been partial and rather lopsided, especially given the rapidly changing nature of the world economy. In part, this is because the meanings of competitiveness are not easily grasped. The new world economy with its emerging, highly interconnected web of companies is far too complex for traditional economic ideas and their derivative policies, which can deal with the new competitiveness only in very limited ways. Too often, the underlying factors of competition – such as research, technology, and innovation – are ignored or seen as being nondynamic, equally accessible features of economies. Compounding all of this, Canada's debate on competitiveness has been notable for an absence of vision and of leadership from governments, business, and academia.

This paper is designed to aid in the debate. It attempts to clarify the linkages between research, technology, innovation, and competitiveness – to get beyond the traditional ideas that have influenced the debate so far. With such an improved understanding, Canada can develop an effective, long-term, wealth-producing position in the new world economy.

Competitiveness: An Elusive Concept

Competitiveness at the Level of the Firm

Although the term "competitiveness" has been used relentlessly in recent Canadian debates about the economy, no comprehensive, fully realistic, or consistent definition has been given to it. Originally, the notion of competitiveness was born out of firm-level economics. At this level, and in very general terms, a competitive firm was one that regularly created and sold a better product or offered a better service than its rivals. Importantly, the firm generally knew who its rivals were since they were usually in exactly the same business, had similar products to sell, and operated in the same markets. On the strength of its products and services, a competitive company was typically one that made a profit and had a large or healthy share of its markets. A firm's first markets were usually nearby – except in the case of large multinational firms. To be competitive, a firm constantly had to try to improve its products and services. It also had to be as efficient as possible, in terms of cost control, in terms of close supplier linkages, and in terms of production processes. Indeed these were often seen as the principal measures of the quality of a firm's management. The world is no longer so simple. And yet it is undeniably at the level of the firm that notions of competitiveness make real sense – it is here and only here that wealth and jobs are created.

Competitiveness at the Level of the Sector

It is important to realize that notions of competitiveness that are based on industrial sectors are problematic. Sectors do not compete: only firms do. A sector is little more than a convenient mental construct that is used either by analysts and researchers, or by people within an industry to connote a grouping of firms that tend to have core products, processes, or markets in common.

Having said this, however, one can talk about the general conditions for promoting or retarding the competitiveness of firms within a sector. From a policy point of view, one might call this setting the environment for sectoral competitiveness. While individual firms succeed or fail largely on

the basis of their actions and reactions to their specific environments, it is equally true that the conditions that are conducive to the competitiveness of firms within a sector vary significantly from one region or country to another. Such conditions are known to be related to the number of firms in the sector, the mix of different-sized firms in the sector, and the size of home market. As the number of firms and the size of the home market both increase, the competition within the sector intensifies. Clearly there are advantages to firms if their sector is geographically clustered. For example, it becomes easier to keep informed about one's rivals, there is a common labour pool with the requisite skills, and technologies or ideas can more easily move from firm to firm. In high technology industries, for example, Canada has rather limited geographical clustering. As a result many Canadian firms are competing against distant competitors. This tends to dull their competitive edge, thin out the available labour pool, and provide little stimulus for the development (in size and sophistication) of a home market.

Thus, as interesting as sectorally based analysis of competitiveness may be, sectoral-level data must be used with great caution because the general observations that may be gleaned from the data tend to have limited applicability for either the individual firm or the analysts wishing to make meaningful comparisons.

Competitiveness at the Level of the Nation

At the level of the nation, the idea of competitiveness is also open to interpretative difficulties. For example, what is a competitive country? It is not reasonable to view competitiveness as being simply a matter of the "average competitiveness" of its firms, but it does make some sense to think of a competitive economy as one with enough competitive firms to keep people employed and prosperous. Moreover, it is not at all clear whether – if one wished to – one could define a nation's firms in terms of the nationality of the firm's ownership² or in terms of whether the firm operates in Canada and thus provides Canadians with jobs, pays Canadian taxes, contributes to Canadian communities, and so on.

Thus, while there are parallels between the ideas of firm-level, sectoral-level, and nation-level competitiveness, the definition of the latter is much more elusive. For example, most analysts would have no difficulty in locating the source of

a firm's strategies and decisions in the firm's management. There would be no end of difficulty, however, in trying to locate similar functions at the national economic level, and there would be outright hostility if attempts were made to equate the roles of firm management with the roles of national governments. There are a great many other such difficulties.

Comparative Indicators of Competitiveness

The Canadian debate has had problems in defining competitiveness in terms of international norms against which Canada should be measured. For example, many Canadians wonder: Is it reasonable for us to expect to compete with countries such as the United States, Japan, or Germany, which have much larger workforces, consumer markets, and capital markets? Or: Is it reasonable for us to try to compete with countries such as Mexico, Poland, or Thailand, which have much lower labour costs? What exactly can we expect from our economy when we have a small but quite well-educated population, a heavy reliance on trade, and a country that is still extremely rich in natural resources?

These types of worries are all legitimate, but they really stem from well-entrenched ideas of the old economic order and do little to advance our understanding of the nature of the new competitiveness. Thus, when discussing the competitiveness of Canada in terms of norms, we rely most frequently on a wide variety of both qualitative and quantitative indicators of our collective and personal standards of living. What is the unemployment rate or the price of groceries this year? Are housing costs taking a higher share of my take-home pay? Can I afford a vacation this year? Do there seem to be more plant closures or homeless people in my city? And so on.

However, there is also a major problem with the use of indicators in the competitiveness debate, as two brief examples will illustrate. Each year, the World Economic Forum publishes *The World Competitiveness Report*. This renowned report has a broad readership but is really of use only to a small number of specialist economists. It has very limited direct applicability to policy making. In the latest version, the WEF published "scoreboards" on 33 countries that combine seven "factors of competitiveness" with 330 "criteria of competitiveness." A complicated and rather subjective methodology is used to weigh each of

these indicators.³ Thus any international rankings that are based on the sum of these 2310 indicators and that compare highly industrialized countries with newly industrializing ones must be interpreted extremely carefully.

While interesting, such measures not only raise the difficult question (mentioned above) of what a competitive nation is, but they also lack any explicit theory to justify and integrate them. Moreover, the process of being competitive, at the firm, sectoral, and national level, is a highly dynamic process that takes place over time: it is more of a motion picture than a snapshot. It is not very helpful, therefore, when newspapers and magazines publish Canada's overall ranking each year (as reported by such organizations as the WEF) without any kind of theoretical underpinning or preamble. As it turns out, the WEF ranked Canada 11th overall in 1982 but now ranks it 5th. If one were a trend-watcher, one might easily be convinced that the Canadian economy is improving, but in the recent debate on competitiveness, policy analysts, media analysts, and business representatives were all arguing over the meaning of our drop from 4th place the year before. Clearly, such casual indicator watching can be misleading without reference to methodology; it cannot tell us much at all about how well we are really doing, regardless of whether the indicators go up or down.

To take a second example, there has been a great deal of discussion over the past decade about the importance of science and technology to the future of our economy. However, it has become fashionable in some circles of both the federal and provincial governments to argue in favour of R&D "targets" at the national, aggregate level. Research and development expenditures at the national level are often measured, and compared internationally, as a ratio – this being the gross expenditure on R&D (GERD) as a percentage of gross domestic product (GDP). Using this measure, Canada has consistently fluctuated around the 1.3 per cent GERD/GDP level for about 20 years. In comparison the U.S. ratio is 2.8 per cent, and Britain's is 2.2 per cent. The blunt argument in Canada's "target" debate is simply that we, as a country, need to set a target and a schedule to increase our GERD/GDP ratio to, say, 2 or 2.5 per cent by the year 2010. The assumption here is that if Canada spends more on science and technology, then Canada will have a "high technology economy."⁴ If we have a "high technology economy," then we will be competitive.

Unfortunately, the relationship between GERD/GDP ratios and competitiveness is not quite so easily made – for a vast number of reasons that can be summarized as follows.⁵ If the people of Canada were to sign a cheque for, say, \$1 billion to be spent on science and technology, and if our cheque were to be cashed tomorrow and divided among the researchers and companies who are already doing R&D, then the real effect on our economy would be minimal. This is because there would be no capacity to effectively use this money. To use such funds for the benefit of the country, and the researchers and firms involved, there has to be infrastructure in place to allow the effective absorption of new investments. For R&D to be productive, university and industrial labs both need high-quality instrumentation and equipment. For research scientists and engineers to be productive, they need assistants with high-quality technical and vocational training as well as good co-researchers with undergraduate and postgraduate training. For firms to turn their R&D investments into new products, services, and profits, they need – among other things – technically literate marketing and administrative staff with a wide range of skills. Moreover, using such macro-indicators as the GERD/GDP ratio as a focus for policy ignores the problems associated with the quality of the research and the source or distribution of the research (be it industry, university, or government) relative to other countries.

Traditional Analytical Approaches to Competitiveness

In the process of analysis, the complexity of competitiveness is too often reduced to single items of concern – the implication being that if we can just fix this one item then Canada, or the industrial

Traditional Focuses in the Analysis of Competitiveness

- Prices
- Costs
- Exchange rates
- Productivity
- Savings
- Cost of capital
- Investment
- Comparative advantage

sector in question, will be competitive. Unfortunately, the identification of lone problem areas, while often important, rarely goes to the heart of the problem of competitiveness. Moreover, by focusing on one or another symptom of competitive decline, traditional analytical approaches have tended to ignore the real dynamics of business and the contributions that research, technology, and innovation are making to the changing ways of creating wealth.

Prices, Costs, Exchange Rates, and Competitiveness

Prices, costs, and exchange rates are often cited by business representatives as being at the centre of their industry's international competitiveness problems. Undoubtedly these are important elements for firms, especially those firms that compete on the basis of cost instead of product differentiation. But analytical approaches that focus almost exclusively on these factors typically do not accurately reflect the changing competitive experiences of firms. Often these approaches hold that export prices are principally determined by industrial costs – most notably, wages. In terms of economic policy, this view has led to a good deal of importance being placed on wage control and currency devaluation as avenues to competitiveness.

This view has seen something of a revitalization in Canada, despite the evidence of Germany, Japan, and Switzerland, which have by all accounts been very competitive internationally, while having extremely strong currencies and high-wage workforces. Moreover, highly respected studies have shown that in the United States and Britain, contrary to traditional analytical expectations, drops in the relative unit wage costs and export prices have gone hand in hand with significant losses of world market share in manufacturing. By contrast, in Germany, Japan, and Switzerland rises in relative unit wage costs and export prices have occurred at the same time as significant increases in world market share. Thus, relying uniquely on prices, costs, and exchange rates is not a trustworthy guide to understanding competitiveness.⁶

There is another misleading aspect of the view that emphasizes labour costs as a negative pressure on the competitiveness of firms. As the Economic Council of Canada has shown, overall hourly wages and salaries in Canada have – when corrected for inflation – remained about constant since 1975. However, a recent U.S. study has

shown that the average Canadian chief executive officer makes 12 times more than the average Canadian shop-floor worker.⁷ This multiple is higher than that for the CEOs in Germany, Ireland, Japan, Korea, the Netherlands, Sweden, and Switzerland. Individual cases that have been cited in the press show that some firms have a salary and compensation package for their senior executives that amounts to more than 1000 times what they pay the average worker. The U.S. study makes clear that these executive pay packages are usually not tied to firm performance and thus raises important questions about business leadership.

Productivity and Competitiveness

If one area of concern is singled out most frequently as a prime determinant of competitiveness, it is productivity. Indeed, Michael Porter's much discussed report on Canada says exactly this: "the underpinning of competitiveness, and thus of a country's standard of living, is productivity."⁸ Productivity is extremely important. It is a measure of how efficiently we are using our workers, our machines, and other means of production. In a sense, though, singling out productivity as the pivotal problem of competitiveness may be pointing to something of a truism. After all, along with long-term survival and the continual search for profitability, isn't the goal of every responsible firm or organization to make as productive use of its resources as is possible? In addition, although productivity growth is an important part of the competitiveness equation in both analytical and firm performance terms, it is not an area that government policies can really affect.⁹

Having said this, Canada's basic level of productivity is high, though the growth in productivity has slowed. From 1979 to 1989, Canada's total factor productivity – which measures the productivity of both labour and capital – rose by a mere 0.4 per cent per year. This was identical to the American performance. However, over the same period, the growth in manufacturing labour productivity in Canada was the lowest of the G-7 countries, averaging only 1.8 per cent per year. This is a worrisome situation because, in general, the more a country can produce per unit of labour or capital, the more its products will be able to compete with similar products of other countries (assuming stable exchange rates). Moreover, a high base of productivity and a high rate of

productivity growth may not be sufficient to make Canadian industries more competitive than their foreign counterparts. We stand to lose world share.

There are many well-known ways to improve productivity, such as updating equipment and machinery or smoothing production processes. But none of these in and of themselves spell long-term competitiveness for Canada or for Canadian firms. None reflect the fact that much of what is happening in the economy is new. Simply becoming more productive at manufacturing uncompetitive products, or becoming more efficient at performing poor processes, will not give us the edge we are seeking. Meanwhile, the sources of our faltering productivity growth continue to be the focus of much debate among economists. Adding to the complexity of the debate is the fact that most measures of productivity relate to manufacturing and tangible processes (such as the number of tons of pig iron produced per hour), whereas more than 60 per cent of Canada's gross domestic product now comes from the service industries and intangible products (such as software). Thus standard productivity measures can give us a distorted picture of what is "wrong" with our economy. Research, technology development, and innovation tend to be such intangible activities. All in all it is difficult to find any solace in approaches based on productivity as a key to competition.¹⁰ Productivity growth remains an important piece of the puzzle, but it is not the whole picture.

Savings, Cost of Capital, Investment, and Competitiveness

Two further factors that are important for competitiveness are the rate of savings and the cost of capital, which affect the level of investment. Together these two factors help determine the degree to which we are able to invest and re-invest in the upgrading of our productive systems and resources. Typical examples of investment requirements are for new plant and equipment, new technologies, and upgraded skills.

Not surprisingly, there is a close connection between a country's productivity growth and the growth in physical productive stock (the amount of net investment), the speed with which it is modernized (which depends on gross investment), and the way the stock is allocated (the types of investment). All are sensitive to the cost

of capital and, in the case of high-risk, high technology operations, the availability of "patient" capital, including venture capital. In the case of the latter, as Richard Lipsey has said, "the idea of venture capital in Canada seems to be something of an oxymoron."¹¹ That is to say, there is a severe limitation on the amount of capital that is available to firms in Canada – particularly small and medium-sized high technology firms – involved in activities that are viewed by the large banks and lending organizations as being "nontangible intensive" (i.e., having nonsecurable assets such as knowledge). Instead, a growing portion of new venture funds are being diverted away from small and medium-sized high technology firms towards expansions, mezzanine financing, and leveraged buy-outs. From 1985 to 1988, the share of risk capital infusions into high technology companies dropped from 60 per cent of all venture capital investments to 32 per cent. Much of the blame for this trend has been placed on professional fund managers – for their lack of expertise in technology ventures – and on the managers of small, technology-intensive firms who, venture fund managers claim, are inept at preparing business plans.

The cost of capital is the price that a business pays for additional financial assets, whether to investors or lenders, taking into account expected dividends, interest, and tax payments. Thus the overall cost of capital depends not only on the sources of funds but also on what the funds are used for – to buy land, buildings, equipment, and inventories. The cost of capital is also important for research and development and for other types of knowledge capital. Not only does R&D compete for corporate funds, but the rate at which research results can be put to use depends on how quickly a firm can modernize its plant and equipment to incorporate new products and processes – the effectiveness of R&D in raising productivity is greatly enhanced if the cost of capital is low enough for businesses to undertake, adopt, and adapt more R&D. Improvements in human capital through education and training of all kinds (including training in advanced research, language, literacy, and numeracy) often depend on access to sufficient quantities of quality, up-to-date equipment. Elementary and secondary education, for example, can benefit from more computers, research and language laboratories, and materials. The availability of any of these forms of capital is sensitive to the cost of

capital. However, our low savings rate relative to competitors such as Japan, our high public debt load, and our high dollar have all had the effect of driving the cost of capital up in Canada.

Overall, it is true that Canada's total investment growth has been quite strong. However, we lag well behind our major competitors in terms of private sector investments that are linked directly with improving productive systems and resources. Between 1980 and 1989, our investment in machinery and equipment as a percentage of GDP was lower than that of most other industrialized countries. Similarly, Canadian private sector investment in research and development as a percentage of GDP was the second lowest of the G-7 countries. Canadian business investments in worker training fell well short of the investments made by Germany, Japan, the United States, and many other industrialized nations. Moreover, anecdotal evidence suggests that, following an international trend, Canadian investments in nonproductive activities (such as moving funds globally and daily to high-interest deposit accounts) are outpacing investments in productive activities by as much as 250 times.

Comparative Advantage, Trade, and Competitiveness

Another traditional area for analysing international competitiveness is a country's comparative advantage, trade levels, and trade patterns. By comparative advantage, we mean the relative export strength of a particular sector of the economy compared with the same sector in foreign economies. It is seen as a way for countries to trade with one another in order to benefit from their differences in resources, skills, and so on. It builds on the observation that no country can be competitive in every sector or industry. Thus the underlying industry mix of a country – and the unique mix of resources that a country has – will shape its pattern of international trade. For example, countries with a highly skilled workforce, such as Germany, will tend to export goods that are skill-intensive. Countries that have unique capabilities in niche markets – such as Canada has in scientific instrumentation, remote sensing, and telecommunications equipment – will tend to have trade surpluses in those sectors.

While comparative advantage and trade are extremely important elements of the competitiveness debate, traditional analytical approaches to these areas tend to model world trade in terms of

a series of static "factor endowments" that seek "equilibrium." Although traditional trade theory does accept that technology and technological capability are potentially important endowments, it tends to assume that technology is unchanging and that the rate of technical change is static. It also tends to assume that the effects of technology in determining comparative advantage and trade can be perfectly substituted by any other factor of production. Clearly such approaches have little to offer government policy since they not only reduce the firm and the nation to mere abstractions, but they cast the highly dynamic worlds of firm competitiveness, trade, and the forces of production as being static.

Whether taken individually or collectively, all of the above-noted traditional approaches to understanding competitiveness tend to suffer from theoretical difficulties and from discrepancies with the real experiences of people, firms, and nations. For example, in the case of trade, it was thought in the 1960s and 1970s that the production costs and production structures in the various industrialized countries (including Canada) were converging and that the expansion of trade would therefore lead to greater specialization. Consequently, it was widely believed that international trade could grow without precipitating massive dislocations of firms and workers, and that the political costs of expanded trade were low. For example, in the machine-tool industry, Germany would capture a large share of the market for some tools while the United States would increasingly dominate in other areas of the market. Expanded trade would only lead to increased company specialization and produce higher incomes for both trading nations. In the world of growing trade – and for all industrialized participants – there would be only winners.

And yet, as we know, there are circumstances in the new competitiveness in which increased international trade produces real losses.¹² These losses can be in terms of lower standards of living, lost jobs, lost industries, lost purchasing power, lost ability to pay for social security and health systems, eroded educational facilities, and so on. These conditions have created significant adjustment problems for governments, businesses, and individuals alike. Two changes in the world trading system have made this point clear in the past decade. The first is the entrance of producers from newly industrializing countries into the markets of the industrialized nations. The second

significant trade change is rooted in the new nature of competition between firms in the advanced countries. Put in its most blunt terms, the Canadian response to the challenge of the newly industrializing nations should not be to panic about competing with the low-wage workers for low value-added activities because we do not want a low-wage economy.¹³ Canadians want – and deserve – high-wage jobs in high value-added industries, for it is these industries that will generate the wealth through which we will be able to afford the health, social security, and education systems that we want.

Canadians sense that the new competition is about rivalry – that it is about winners and losers and increasingly about international competition. Moreover, many successful Canadian firms are also beginning to realize that the new, long-term competition is increasingly based on intangibles such as research, innovation, and people – that it has to do with nonprice factors such as quality, corporate strategies and attitudes, and organizational patterns. These – along with staying near the forefront of research and innovation – are the underlying determinants of competition, not simple productivity or costs per se. The source of our future wealth is latent in our people and in their ideas. The site of our future wealth is to be found in the types of companies and the mix of industries that we can attract and develop. The environment conducive to productive wealth creation can be greatly stimulated and enhanced by government policies.¹⁴ But still the question remains, “what are the new forms of competing?”

What Is New about Competitiveness?

Everywhere there are signs of a shift in the nature of competition. Among the more profound shifts – to which Canada must respond – are the following:

- 1) *A fundamental redefinition of the manufacturing company is taking place.* The manufacturing company is traditionally a site for production, and the economist's formulation of production is the production function: that is, the mix of capital and labour that is required to make things. But the new manufacturing firm is beginning to invest more in its research and development of new products and processes than it is in capital. Indeed, in Japan in 1986, R&D investment surpassed capital investment in manufacturing, and the change occurred rapidly. This is a signal of fundamental change,

What Is New about Competitiveness?

- A fundamental redefinition of the manufacturing company is taking place.
- There are deep changes taking place in the definition of a firm's business.
- Competitive firms are increasingly evaluating their core strengths, not on the basis of end products but on the basis of core competencies.
- Many competitive firms are rapidly moving towards lean – versus craft or mass – production.
- The very concept of value added is changing from what we have to what we do.
- There are major changes taking place in the technology development process.
- There are major changes taking place in the patterns of technological innovation.
- Increasingly, the underpinnings of the new competitiveness are based on social innovation.

for if R&D investment is thought to be more important to the competitive position of a large number of such firms, then they could be said to be changing from being a site for production to a place for thinking.

- 2) *There are deep changes taking place in the definition of a firm's business.* Today, technological diversification has progressed so much that it is hard to distinguish between a firm's principal and secondary businesses. In Germany, Japan, and the Netherlands, for example, the once principal business of many firms has been overtaken by secondary business. Or, in other cases, competitive firms are actively redefining their core businesses; steel companies, for example, are moving away from steel towards new materials and (in the case of Japan) biotechnology. Thus, competitive firms are finding that their rivals may no longer even be in the same industry as they are. Such businesses are moving from visible to invisible enemies. Less successful firms are seeking corporate diversification through mergers and

acquisitions. According to several analyses of North American mergers and acquisitions, however, corporate growth through diversification is surprisingly low, and many attempts at diversification along these lines have ended in failure.

- 3) *Competitive firms are increasingly evaluating their core strengths, not on the basis of end products but on the basis of core competencies.* No longer are top managers in competitive firms being judged on their ability to restructure, unclutter, and de-layer their corporations. Today, they are being judged on their ability to identify and cultivate the core capabilities of the firm. They are, in effect, having to rethink the idea of the corporation itself. A core competency involves the collective learning or knowledge of a firm, especially as it relates to the coordination of diverse production skills and the integration of multiple streams of production technology. It involves the flexible organization of work – so that the isolated cost centre or strategic business unit is no longer seen as optimal productive organization – and the clear expression of corporate values. Firms that understand their core competencies ensure that technologists, engineers, and marketers have a shared understanding of customer needs and the technological possibilities.
- 4) *Many competitive firms are moving rapidly towards lean – versus craft or mass – production.* Craft producers use skilled workers and simple but flexible tools to make custom-designed products one at a time. Mass producers tend to use narrowly skilled professionals to design highly standardized products made by unskilled or semi-skilled workers with expensive single-purpose machines. Jobs are broken down into small, easy-to-master steps, permitting the employment of inexperienced workers. Lean producers are employing teams of multi-skilled workers at all levels of the organization and use highly flexible and increasingly automated machines to produce volumes of products in enormous variety. There is a major implication in the flexible and automated lean production system. It is possible both to attain economies of scale and to offer variety.
- 5) *The very concept of value added is changing from what we have to what we do.* No longer are competitive firms adding value simply by working more efficiently with their raw materials – be they wood, silicon, or semi-fabricated components. Instead, these firms are migrating. If their traditional business is in raw materials, then they are moving their product lines up through processing, semi-fabrication, componentry, subsystems, and full systems. Staying at the low end of the new value-added chain will only mean increasing competition with firms in low-wage economies. As world resource prices continue to fall and new suppliers continue to enter the market, a firm's ability to pay fair Canadian wages, upgrade technology, or to migrate the business, will only be eroded. This is important to realize because Canada still depends heavily on resource commodities to generate its trade surplus – which it uses to pay for sophisticated machinery, medical equipment, and so on. Many of Canada's competitors, having situated their principal businesses at the high value-added end of the chain, are migrating their businesses down the chain and in so doing are both strengthening their own supplier linkages and setting the terms for operation in those downstream activities.
- 6) *There are major changes taking place in the technology development process.* In the most advanced technology areas, the key issue for technology policy has become not how to break through technological bottlenecks, but how to access best-practice research and technologies and put them to the best possible use. Accordingly, a day of reckoning is coming for technology policy, which has traditionally concentrated on the supply side of technology (funding of basic research, technology creation, and so on). Increasingly – and rapidly – technology policy will need to deal with the demand side of technology, and in particular with demand articulation. Through this process, the need for specific technologies can manifest itself and the R&D effort can be targeted toward accessing, developing, and perfecting them.
- 7) *There are major changes taking place in the patterns of technological innovation.* Conventional wisdom holds that technological innovation is achieved by breaking through the performance boundaries of existing technologies. With regard to new fields such as optoelectronics and mechatronics, however, it would be more appropriate to view leading-edge technological innovation as fusing different types of technology rather than as technical breakthroughs.

Canada seems to be more active in the more traditional style of technological innovation.

- 8) *A final important shift underpinning the new competitiveness has to do with the social innovation associated with technology diffusion.* The widespread generation and utilization of information technology (IT) throughout IT and non-IT sectors of the economy is possible only after a period of adaptation in the social organization of firms and social institutions. This adaptation is one that opens the organization to the potential of the new technology. Although technological innovation can happen very rapidly, there is usually a great deal of institutional inertia to overcome. Diffusion relies on a succession of firms identifying, adopting, and adapting a technology of potential use.

A Framework for Growth: Research, Technology, and Innovation

As Richard Lipsey has recently reminded us, research, technology, and innovation are the driving forces underlying competitiveness¹⁵ in high value-added firms and advanced industrial countries. However, there is almost as much confusion about what these terms really mean as there is about competitiveness. For example, innovation is most often thought to refer only to technological innovation. This is too narrow. Innovation is a broad and dynamic process that applies equally to the technologies, product development, production-process smoothing, management, marketing, organization, and learning capability of a firm. So a technical breakthrough or technology fusion may well be based on one or a series of technical innovations, but it may not be identified or used effectively unless the firm itself can reorganize, or is already flexible enough to internalize the technology. This involves social innovation. Thus an innovative firm does not have to be in a high technology industry. It may use the technology for its internal purposes (word-processing pools or inventory control) or production purposes, in which case the technology becomes embodied in the business and products or services of the firm. Or it may begin, as its main business, to create, modify, or assemble the technology itself (as in the case of computers, numerically controlled machine tools, and so forth).

Technology

Technology is knowledge that is embodied in an artefact. It contributes to the creation, fabrication, and improvement of economically and socially useful products and services. Such knowledge relates not only to physical artefacts but also to forms of organization needed for their production, distribution, and use. We clearly depart here from the widely held assumption that technology is simply a form of "information" that has the properties of being costly to produce, but virtually costless to transfer and to use. On the contrary, technological knowledge is mostly tacit (that is, it cannot be made fully explicit in the form of instructions), is embodied in individuals, and is mainly firm-specific. Technological knowledge is not largely generated by basic research activities, but is instead developed by firms to improve specific product lines or to solve specific problems. Depending on the type of technology, industry, or firm, such activities may be defined in terms of design, development, or production engineering.

Technological know-how and technology acquisition for firms is a cumulative and highly specific process. For example, two firms that make, say, light bulbs, may do so based on very different core technologies, core competencies, and corporate cultures. Given the firm-specific and highly specific nature of products, processes, and related technological knowledge, the majority of firms tend not to engage in broadly based in-house research, but instead tend to closely watch technology and market areas that are germane to their existing activities. What firms try to do technologically in the future is strongly conditioned by what they have been able to do in the past.

Basic Research

In many instances, at the defining edge or frontier of much technical innovation is basic research. It is most often thought of as an international activity that is (mostly) publicly funded and carried out in universities. Its principal output is usually the publication of research results in scientific journals. As a result, the national benefits of basic research do not stop at national borders. Attempts to deliberately contain basic research by isolating it from international exchange are counterproductive not only to science, but to the rapid advance of scientific understanding and ultimately to the advance of the society funding it. This "free-

floating multinational" character of basic research does not imply that it has little economic value, nor does it suggest that basic research does not factor into the competitive advantage of firms and nations. In fact the opposite is true.

Basic science has strong economic ties (i) in its own right as a form of intellectual consumption, (ii) as a foundation to the technical training of future generations of researchers and technicians, (iii) as a source of fundamental knowledge needed to solve practical problems, and (iv) as a source of future generic or strategic technologies. It is for these reasons that a great many large firms are constantly involved not only in monitoring basic research results, but in contributing to and using them. It is also for these reasons, although in a decidedly more constrained and focused way, that many small, very high technology firms engage in basic research.

Having said this, it is important to recognize that there are two extreme, but still popular, models of the linkage between science, technology, and innovation that are not valid. Unfortunately, they still seem to have currency – especially in policy circles – and must be discarded. The first can be described as the "science push" or "linear" model, where "R leads predictably to D" and then to innovation (defined here as the first commercialization of a product or process), and diffusion. The second model can be described as "demand pull." It assumes that the rate and direction of technological change are by-products of other forms of economic activity: in particular, investment in plant and equipment is assumed to be the means through which innovations are commercialized. Both these popular models ignore the vital importance of interaction between research, corporate culture, and the market or users. They ignore the considerable variations among sectors, products, and technologies. They ignore the institutional sources of knowledge and the growing importance of (and problems associated with) inter-institutional linkages (as in university-industry and inter-firm connections). They ignore the unpredictability or serendipity of all research. And they assume that "science" feeds evenly into "technology" at a consistent or dependable rate. In fact, while the relationship between science and technology is known to be extremely important, it is also very poorly understood.

As a result of the economic importance of basic research, it is important to underscore four critical reasons for its public support. First, if left to itself, a market will tend to invest less than is optimal in

basic research because a profit-making firm can never capture all the benefits of the research that it sponsors. Second, basic research underpins the development of strategic technologies, which ties a firm into the international marketplace and which ties a country – via its researchers – into the world pool of new knowledge and new technologies. Third, facilities for basic research form an important part of a nation's infrastructure for future technological and productive activities. Fourth, basic research provides the critical training and research skills needed for the development of many future employees.

Strategic Technologies

Strategic technologies are so called because they have a firm footing in advanced research and an extremely wide applicability across industries and sectors. It is a characteristic of strategic technologies – such as microelectronics – that they transform entire industrial sectors while creating new ones. It is characteristic of strategic technologies that a large portion of their knowledge base lies in the public domain in the form of published papers and patents. In part this is due both to the novelty of the technologies themselves and to their rate of development. These features create an incentive for firms and researchers to keep informed about alternatives to those technologies that the firm is currently backing. In some sectors, it is essential for a firm seeking to be at the forefront to have an in-house knowledge base that enables it to monitor and absorb knowledge from public sector research institutions – most notably, universities. This is even (perhaps especially) important for smaller firms near the forefront, as it is (albeit in a different way) for firms following an adopt and adapt strategy. It is because of the knowledge-intensive, rapidly developing, and public nature of these technologies that firms increasingly are moving into collaborative arrangements. These arrangements include research consortia (in which companies and university labs share recent results), contract research, joint ventures, and strategic alliances.

Leading firms in strategic technologies tend to be drawn along a technological trajectory that improves their performance and leads them into new products with high growth in demand. Their technologies often spill over into adjacent sectors, creating in turn new technologies, new products, and at times new industries. Conversely, firms that are well behind the technological frontier –

both as generators in some niche areas, and as users in broader areas – may find that their future performance is “dynamically penalized” by their current industrial structure. In such a case, the national economies drift into lower value-added production and exports. One of the challenges to Canada is to shift its industrial mix into more, not less, value-added production and exports. This underlines the importance of strategic technologies and innovation.

By being active in strategic technology areas and by defining narrow niche areas in ways that build on indigenous strengths and market opportunities, a nation's industrial structure can be made more knowledge-intensive and more competitive. In Britain, France, Germany, Japan, Sweden, and the United States, for example, carefully defined strategic-technology niche areas and niche policies have been set or sought. These countries – our competitors – believe that by focusing on certain specific capabilities, they will move their industrial structure into higher value-added products and processes. In Canada, by contrast, we have not yet identified key niche sectors or technologies, nor have we adopted a more dynamic understanding of value added. This is true despite the fact that we have superb indigenous capabilities in such important technology areas as remote sensing, satellite technologies, advanced software, energy technologies, and so on. Canada needs a clear, well-articulated, goal-oriented innovation strategy.

Despite the critical contribution that basic research makes to the competitiveness of a country, it is its role with regard to strategic technologies that most often is of interest to policy makers. As has already been suggested, the general importance of strategic technologies stems from the fact that they set the performance standards for the next generations of technology and they are applicable in a wide variety of industries and products. They can be generated and developed by a large number of industries, and they can be “stretched” or modified over time to underpin subsequent families of technology. However, to fund basic research on the expectation of developing strategic technologies is shortsighted and only follows the now-dead linear models.¹⁶ Indeed, it may seem unusual that disparate technologies – such as informatics (information plus communications technology), biotechnology, and new materials – are being clustered together by policy makers and afforded similar special treatment as

strategic technologies. After all, there is much that they do not have in common. Some form the basis for enormous international industries while others, such as high-temperature superconductivity, are little more at the moment than promising laboratory phenomena. What they do have in common, however, is that they are knowledge-intensive and they are likely to become pervasive. (It is these characteristics that have contributed to Japanese firms spending more on R&D than physical capital).

Successful Firm-Level Innovation

Firm-level innovation must be seen as being more than just research and technology. More broadly, it has to include development and design activities, finance and marketing, market surveillance, firm organization, and firm strategy. Competitive firms, regardless of size or industry, have to be innovative. But innovation is multifaceted. There are no simple, single-factor explanations. However, factors underlying successful innovations are fairly generalizable.

Successful Firm-Level Innovation

Successfully innovative firms

- are people-centred;
- forge extremely strong end-customer linkages;
- are internally integrated;
- see innovation as a corporate-wide task and set the conditions for innovation.

- 1) *Successful innovation is people-centred.* It is based on competence and an ethos that encourages and rewards creativity and innovation wherever they may be found. Formal management techniques can enhance the performance of competent managers, but they are no substitute for management of high quality and ability. Just as research and technological innovation are the result of creativity and insight (people-centred characteristics), so too is successful innovation dependent on key individuals – top management, technological gatekeepers, and product champions.

- 2) *Successfully innovative firms forge extremely strong end-customer linkages.* Traditionally, the role of marketing is to scan the marketplace to identify new and evolving customer requirements as a basis for initiating new product developments or modifying existing ones. This is a passive, or at best reactive, attitude, regarding the user as simply responding to a marketer's questionnaire. The marketers then assess the answers for themselves and feed what they feel is appropriate into the product development or design function. The interaction ends there. In high value-added competitive firms, however, the user is seen as an integral part of the design and development process. Product improvement is based on a relentless focus on customers' needs and markets. Strong customer service, customer training, and follow-up are key.
- 3) *Truly innovative firms are internally integrated.* In firms where functions are separated – competing strategic business units, for example – products or product ideas are essentially “thrown over the wall” to the next group that has to deal with it in order to get it to market. There must be integration of management, ownership of the new product or idea, corporate sense of direction, and feedback from the market to the engineers. Without these there will be no impulse to improve products, processes, or services. The firm will not be in a position to set the terms for competition and will be forced to accept the terms set by a rival.
- 4) *High value-added competitive firms see innovation as a corporate-wide task and set the conditions for innovation.* Top management must be seen to be receptive to risk, as well as committed to and supportive of innovative ideas and practices. There should be a long-term commitment to major projects and there should be, to the extent possible, a willingness to seek finance internally.

Just like firm-level innovation, successful innovation at the level of the nation must be seen as involving much more than just research – although, again, a critical (and healthy) mass of research and development is essential for the development of a competitive nation. Innovation depends, for example, on the culture of the nation – on the willingness of its people to learn and to put their know-how and vision together in action.

It depends on the ability of the country to constantly enhance its technological capabilities. Successful innovation (and “imitation,” which is the “next best practice” upon which all countries including Canada depend for diffusion) requires high levels of technological activity to be performed and financed by firms. It requires publicly funded systems of basic research, which provide skills, instrumentation, and delivery of know-how to practitioners through a multiplicity of channels. Over time, the mix between innovation and imitation (in both science and technology) will and should change, reflecting the fact that a nation is either moving towards or away from the world's best practice.

It should be realized that successful innovation and imitation does not come cheap or easy. The infrastructure for innovation in Canada must be continually built up and maintained at international best-practice levels. This necessarily requires strong and interlinked policies for research, training, finance, management, communications, and even transport. Imitating best practice German, Italian, or Japanese technology is difficult, not only because of the technical aspects but also because of distance and language. Many Canadian firms – though nowhere nearly enough – have recognized the importance of person-embodied knowledge transfers and have pursued a variety of activities through which to enhance their technology and marketing capabilities. These have ranged from personnel exchanges with universities and R&D labs to foreign-language courses and joint ventures.

Can Canadians Really Lose Out?

Canada has some superbly innovative firms and some extremely strong research and technology. Our standard of living is high. We still have strong social security systems. Canada is a small country that has a surprisingly big economy.¹⁷ And Canada has a very positive international reputation – geopolitically, environmentally, and as a place to live.¹⁸

However, Canada is vulnerable because it is still dependent on undifferentiated resource industries for a large part of its wealth creation. We are heavily dependent on trade with the United States, and our trade pattern is narrowing. We are technologically dependent and our industrial structure is narrow. Canada contributes roughly 2 to 4 per cent of the world technology

pool and 3 per cent of the world research results. Our high technology trade balance shows a \$7 billion deficit. More than 75 per cent of our exports go to the United States, while a mere 6 per cent go to Japan. Although we have tremendously talented individuals and firms, more than 65 per cent of all our industrial R&D is done by only 100 firms. Our high technology exports are concentrated in four commodity groups: aircraft and associated equipment, telecommunications equipment, ADP machines, and non-electric engines and motors. Our federal deficit, and the emphasis of most firms on the "bottom-line, quarterly statement," is squeezing our ability to save and re-invest in productive activities. Many argue that Canada probably has too many lawyers per capita¹⁹ – as compared with Germany, Japan, and Sweden – and that we need more engineers, scientists, teachers, and entrepreneurs. Canada's population is aging rapidly and will be requiring the services of our health care system in increasing numbers. As it is now, we are not creating enough wealth to be able to pay for this surging demand on the health care system.

Surveys regularly point to the fact that Canadian managers do not understand research, technology, or innovation, and prefer to focus on short-term finance and sales. Other surveys show that our business and engineering schools offer ludicrously few courses in technology management, technology policy, or the economics of R&D.²⁰ They are training for a marketplace that existed 20 to 30 years ago.

It is clear that we are not adjusting to the new competition fast enough. Between 1971 and 1986, Canada's high technology exports as a proportion of total exports increased from 11 to 14 per cent. During the same period, the proportion of high technology exports rose from 27 to 38 per cent in the United States, from 12 to 28 per cent in Japan, and from 9 to 24 per cent in the newly industrialized countries of Asia. Contrary to the optimistic expectations of the 1960s and 1970s, the world economy is not the exclusive terrain of the industrialized countries. The world economy grew by only 1 per cent in 1990 and was growing even more slowly in 1991. Almost all the growth is taking place among our competitors. In 1990, the economies of Latin America shrank by 4 per cent, Eastern Europe by 11 per cent, and the Soviet Union by 14 per cent. There is nothing magical sustaining the Canadian economy or the Cana-

dian standard of living. Canadians *can* lose out. If we are to compete, we have to work and we have to invest – in our people and in our firms. We have to innovate. And we have to create a climate that stimulates competition on the basis of final customer needs, high value added, and a vision of the way we want Canada to be.

But where is the clear leadership from our politicians, entrepreneurs, employees, and teachers? We need everyone pulling together. What we need from our leaders is a very clear agenda for action – even if it seems controversial. But most are too preoccupied with the trees to see the forest. Our leaders must be willing to take unpopular stands when necessary. And when such stands are necessary, they have an obligation to explain their positions to their constituents. They must solicit the support of their constituents and win not only their approval but their involvement. Canadians know that we must work to shed the "woodshed of the OECD" image. The linkages between research, technology, and innovation – coupled with a belief in people – give us the building blocks.

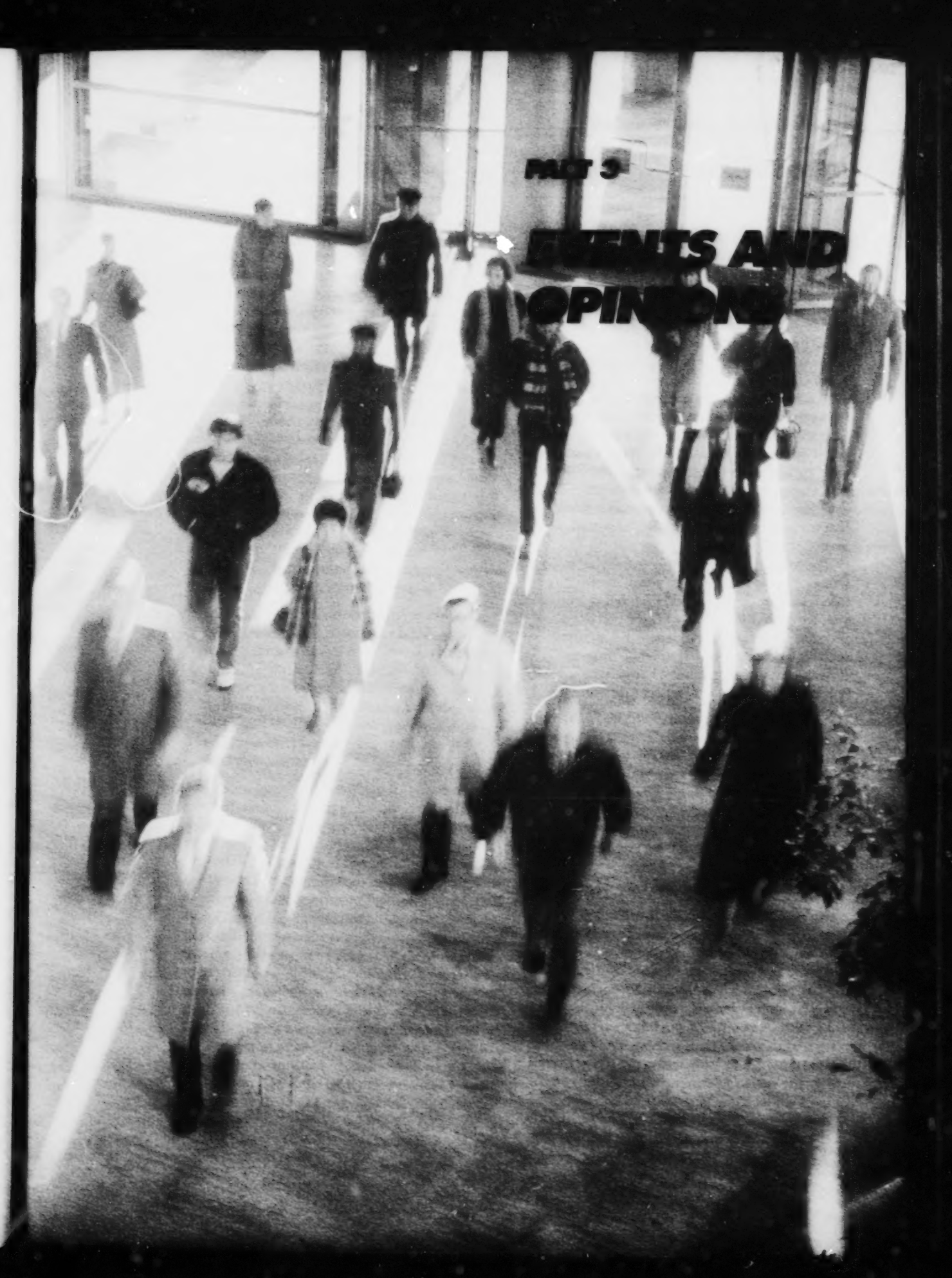
A first step in making Canada more competitive is for our leaders to take responsibility for ensuring that every citizen realizes what being competitive really means and why it is important to every individual. In this way, the vision of Canada's leaders can be translated into reality. To date, however, such leadership has not been forthcoming. There seems to be a preference in some business circles for opinion over vision and a reliance in academic circles on old practices, while some government circles seem to have opted for a process of excessive – or at least, unfocused – consultation. To be sure, consultation is an important element in our parliamentary democracy. But it has practical limits. Unless clear questions are asked, and clear mechanisms exist through which to translate business and public concerns into action, there is a real danger that Canadians will see consultation processes as mere proxies for leadership – as indications of the absence of vision. And, after all, competitiveness – like research, technology, and innovation – is a visionary activity.

Notes

1. These terms have been used by *The Financial Post*, *The Toronto Star*, and *Le Monde diplomatique*.
2. The question of the importance of firm nationality, at a time when finance, technology, and markets are independent and fluid, is increasingly being debated. See Robert Reich, "Who Is 'Us'?" in his *The Work of Nations* (New York: Knopf, 1991); and Richard Lipsey, *Economic Growth: Science, Technology and Institutional Change in a Global Economy* (Toronto: Canadian Institute for Advanced Research, 1991).
3. World Economic Forum, *The World Competitiveness Report, 1991* (Lausanne, 1991), 9.
4. Given the dynamic and embedded nature of research, technology, and innovation, it is not at all clear what a high technology is, nor is it clear what a high technology economy is. Every economy involves a mix of activities, and cannot truly be built on one type of activity.
5. It should be remembered that international macro-indicators such as the GERD/GDP ratio are exceedingly complex compilations of national expenditure data, the interpretation of which can be distorted quite easily. For example, if a nation's GDP drops while the overall expenditure on R&D remains constant then the GERD/GDP ratio will go up. Clearly such an event does not suggest a greater national commitment to science and technology.
6. For an early illustration of this view, see Science Council of Canada, Industrial Policies Committee, *Hard Times, Hard Choices*, Statement (Ottawa, 1981).
7. See, for example, Graef Crystal, *In Search of Excess* (New York: Norton, 1992); and *La Presse*, Montréal, 12 November 1991, D11.
8. Michael E. Porter and the Monitor Company, *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Business Council on National Issues and Minister of Supply and Services, 1991), 5.
9. John Zysman, *Government, Markets and Growth* (Ithaca: Cornell University Press, 1987).
10. For a review of the limits of productivity and productivity growth as measures of the new competitiveness, see, for example, James K. Galbraith, "A New Picture of the American Economy," *The American Prospect* (Fall 1991): 24-36.
11. Richard Lipsey, luncheon address to the Committee of Parliamentarians, Scientists and Engineers (COPSE), October 1991.
12. John de la Mothe and Louis Marc Ducharme (eds.), *Science, Technology and Free Trade* (London: Pinter, 1990).
13. Compounding such competitiveness is the development of high-skill but low-wage occupations (such as computer assembly) in semideveloped nations. Where countries such as Canada still have a comparative advantage is in the creativity that leads to the design of high value-added products and processes.
14. As the OECD has pointed out, science, technology, and innovation policies do work. See Henry Ergas, "Do Technology Policies Matter?" in Bruce R. Guile and Harvey Brooks (eds.), *Technology and Global Industry* (Washington, D.C.: National Academy Press, 1987).
15. Richard Lipsey, *Economic Growth: Science, Technology and Institutional Change in a Global Economy*, op. cit. Of course, this observation has been demonstrated empirically and argued theoretically throughout the past 25 years in the publications of the Science Council of Canada, the Science Policy Research Unit (University of Sussex), the Program for Research on Engineering, Science and Technology (University of Manchester), the Berkeley Roundtable on the International Economy (University of California), and many others.
16. Nathan Rosenberg, "Critical Issues in Science Policy," *Science and Public Policy* (December 1991): 340.
17. Canada ranks fourth in terms of gross domestic product per capita.
18. Canada ranked second in a recent United Nations survey of desirable places to live.
19. Ontario has 39 times as many lawyers per capita as Japan.
20. In 1982, a Science Council survey showed that there were more than 100 programs in these areas in the United States and Europe and more than 750 individual courses. In a growing number of U.S. graduate schools, the MMT (masters degree in the management of technology) is challenging the MBA. In Canada today, there are roughly 75 courses being offered across the country. Only an estimated 18 of these courses are offered through business, administration, and management graduate schools.

PART 3

EVENTS AND OPINIONS



Introduction

Part 3 provides a brief overview of the main events in science and technology policy in 1991. It is divided into five chapters to cover five broad (and overlapping) policy areas: education, industrial innovation, impacts, infrastructures, and new frontiers. Woven into the summary of the principal events are the comments and opinions of a variety of participants in the science and technology policy debate.

The five chapters are presented in the order of importance identified by readers of the Science Council's newsletter, *In Touch*. In a survey in July 1991, readers ranked "education, training, and literacy" as the most important of the five policy areas for study, and "new frontiers" as the least important. It should be stressed, however, that the majority of readers felt it important to investigate all five areas.

The treatment is necessarily somewhat selective: one could focus on any one of the five interrelated policy areas and find that in a given year a tremendous amount is going on in policy, programs, advocacy, and debate. For this first review, for example, the chapter on impacts focuses on aspects pertaining to the environment. Subsequent reviews may reflect a different approach or emphasis.

1. Education, Training, and Literacy

The unavoidable conclusion from the reports and the surrounding debate on education in 1991 is that a consensus is emerging in Canada that must lead, ultimately, to fundamental changes in the country's educational system. The question is whether change will happen sooner rather than later. This section will review some of the major events and opinions shaping the discussion.

The momentum for change is the growing recognition, first among scholars and now increasingly among employers, parents, educators, and politicians, that Canada's future prosperity in a global, knowledge-intensive economy is crucially dependent upon the enhanced education and training of its people. The realization that education must extend beyond the acculturation and "empowerment" of the individual to consider society's broader economic and social requirements was reflected, at the federal level, in the May 1991 Speech from the Throne:

Increasing economic prosperity is first and foremost an issue of people. Canada's ability to prosper in a global economy will be determined by the level of Canadians' education achievement, by the sophistication of our management skills and by our attitudes to work and to change. In the dawning knowledge age, how well we live will depend on how well we learn.

This message was reiterated by the government in the subsequent publication of two consultation papers, *Prosperity through Competitiveness and Learning Well...Living Well*.

An international perspective was provided by the World Economic Forum and the International Management Development Institute in their 1991 *World Competitiveness Report*. Although, as mentioned in the previous section on competitiveness, this document must be read with close attention to its methodology and limitations, it nevertheless served as a further reminder that the availability of skilled human resources was as significant to Canada's economic performance as industrial efficiency and financial dynamism. Our poor ranking in people factors, defined by poor worker motivation (16th), the high number of industrial disputes (16th), and limited availability of skilled

labour (15th), contributed to Canada's drop from fourth (in 1990) to fifth place in the world competitiveness standings.

The dialogue on education, training, and literacy also involved social issues such as poverty, drug abuse, violence, and hopelessness, as indicated in the Organisation for Economic Co-operation and Development's 1991 *Employment Report*:

The increased incidence of unemployment is affecting the living standards and welfare of many people and their families, adding to the problems of poverty and social exclusion. Moreover, those entering unemployment risk losing skills, motivation, and the capacity to work and to learn new skills.¹

For Canada, with its high unemployment levels in 1991, the danger that a growing number of Canadians would enter the unemployment-poverty-illiteracy cycle was heightened. This cycle, once considered to be a problem for citizens of developing countries, is a growing reality for citizens of developed countries, including Canada.

Who then has the responsibility for improving Canadian education, training, and literacy? In September, the federal government presented its constitutional proposals for national discussion. Its proposal to transfer certain responsibilities, such as labour market training, to the provinces served to re-ignite the debate regarding national educational standards, training, and testing. These are among the issues examined below.

Elementary and Secondary Education

The call for national educational standards was prominent in the discussion on education in 1991. It found new and vocal allies in the business community, which brought the lexicon and management practices of business to the discussion. For example, many industry leaders expressed the view that education requires the application of market forces to keep it competitive. Robert Kennedy, chairman and chief executive officer of Union Carbide, in his address to a conference on education and business sponsored by the Conference Board of Canada in April, contrasted how business and education assess their health:

If you and I want to know how good our companies are, we ask the stock market. We learn quickly from our customers. We listen to the security analysts, even when it hurts. We pick up the annual reports of our competitors. Schools don't have that continuous feedback. They don't have competition; therefore they don't have competitive benchmarks.

How can the educational system set competitive benchmarks? For Thomas D'Aquino, president and chief executive officer of the Business Council on National Issues, "Standardized tests are one way to introduce excellence into our educational systems. The tests set goals for people to shoot at."²

Some teachers and school administrators, on the other hand, question the value of national testing for students and ask: How does one measure excellence? Geraldine Kenney-Wallace, president of McMaster University and former chairman of the Science Council of Canada, suggests that:

The concern over testing is deeper than just an argument over whether testing will reveal what you wish to know. It is also an argument about who is going to compare my students with your students, this school against that school, this province against that province.³

In any case, the use of national standards testing is increasingly being viewed not only as an assessment of student knowledge but as a performance and accountability measure for teachers, schools, and school boards.

As for tangible initiatives regarding the implementation of educational standards, the Council of Ministers of Education had the support, until the middle of the year, of all the provinces for a pilot testing project (School Achievement Indicators Program). Beginning in 1993, this national program would test the reading, writing, and math skills of 13- and 16-year-olds. In the spring, Ontario rescinded its participation in the project, claiming that the tests would not take into account the ethnic diversity of Ontario students or reflect what students were being taught in school.⁴ In December, however, education ministers from all provinces except Saskatchewan agreed to nationwide school tests. Saskatchewan's new minister of education indicated that a decision to participate in the project would be forthcoming after consultations had been conducted in

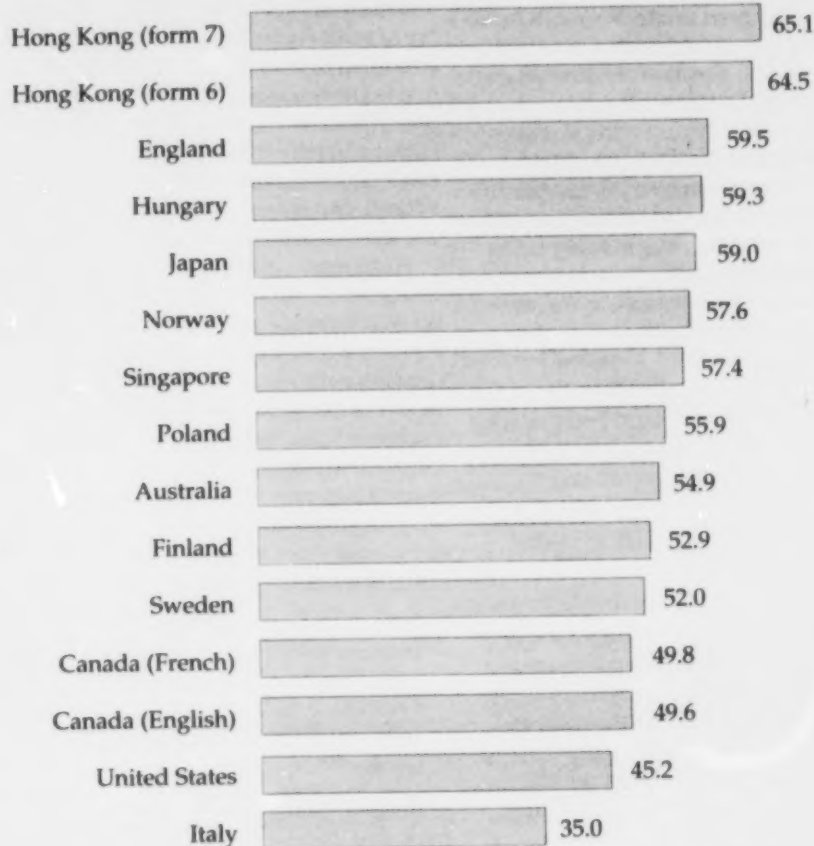
her province. Regardless of the outcome of this project, some provinces, such as Alberta, are committed to measurement tests and have taken steps to institute provincial testing. In October, the Alberta minister of education unveiled a blueprint for the next decade that included more provincial testing and basic skills development as well as clearer guidelines on what is expected from teachers and students.⁵

The federal government advocated national educational standards in *Learning Well...Living Well*, released in November. It suggested that national standards and measures are necessary for portability, mobility, and consistency. They would enable individuals to move with comparative ease through different educational institutions at different stages of their lives. The document also suggested that performance measures would allow individuals to compare educational institutions. The federal government, however, offered no strategy or plan for developing national standards or for resolving any of the other issues challenging Canada's competitiveness. It did say that it would consult with Canadians to find the solution through a prosperity secretariat (consisting of about 30 federal bureaucrats as well as private sector committees), public meetings, and public awareness programs. Given the spate of consultations that Canadians have been asked to participate in over the last two years and the economic downturn of the past year, it was not surprising that support for this process was weak. As John Bulloch, president of the Canadian Federation of Independent Business, put it:

We are being savaged out there and [the federal government] wants to get us involved in a one-year-long talkathon. There are a bucketful of studies that have dealt with competitiveness issues. Action should have been taken already.⁶

The achievement of national standards possibly became more difficult when the federal government released (in September) its constitutional proposals in *Shaping Canada's Future Together*. The document acknowledged that the responsibility for education has always been the domain of the provincial governments and stated that it should remain there. But in addition it proposed to transfer federal labour-market training functions to the provinces. This transfer was seen, by some, as a contradiction in policy objectives. How could the central government set national standards and at the same time abandon its role in training?

Figure 1. Second International Science Study, End of High School, Science Specialists, 15 Industrialized "Countries," 1983-1986
(per cent correct, adjusted for years of schooling and retention rate)



Source: Judith Maxwell, Chairman, Economic Council of Canada, "Notes for an Address to the National Forum of Science and Technology Advisory Councils," Victoria, B.C., 30 September 1991.

Science Education

The relatively poor performance of Canadian students in high school in math and science programs was assessed by the Economic Council of Canada, drawing on data from the Second International Mathematics and Science Studies. Even after the results were adjusted for differences in years of schooling and retention rates, Canadian students finished near the bottom of the list, as indicated in Figure 1. (Only British Columbia and Ontario participated in the mathematics study, while all provinces participated in the science study.)

Some researchers, however, are cautious about the usefulness of such international indicators because cultural and policy differences between countries confound the interpretation of the results (for example, by comparing students in a general study program with those who are "streamed" into science programs). It has also been suggested that the hunt for performance indicators is driven by the search for accountability measures.⁷ If this is the case, perhaps it would be more meaningful to measure how well the educational system is meeting local expectations and a school's declared mission. Although the

Economic Council describes this as "largely uncharted territory, raising formidable questions about concepts and measurements,"⁸ policy direction for education will be difficult to define without better information.

A widely accepted prescription for improving science education has been available since 1984 in the Science Council of Canada's report *Science for Every Student: Educating Canadians for Tomorrow's World*. A recent informal survey of provincial science curriculum initiatives revealed that many of the report's 47 recommendations have been incorporated in full or in part by all ministries of education. British Columbia, in particular, quickly adopted the recommendations as ministry policy. Although it may be coincidental, it is noteworthy that British Columbia's performance in the international science study exceeded that of all the other provinces.

In 1990, the House of Commons Standing Committee on Industry, Science and Technology, Regional and Northern Development heard business, professional, and trade associations and educators strongly advocate the need for more math and science education in Canadian schools. The Committee's final report, *Canada Must Compete*, stated:

Witnesses impressed upon Committee members the need to instill a greater awareness of science in young students.... The low profile accorded science and technology in Canada and the lack of interest among students in pursuing science careers must be addressed immediately. If Canada fails to create a scientifically literate labour force it will not be able to compete in the global economy.⁹

Ottawa's specific response to the call for support for math and science education was to point to existing public awareness programs, such as Science Culture Canada and National Science and Technology Week.¹⁰ A discussion paper on science and math education by the Conseil de la science et de la technologie du Québec noted that, aside from the Science Culture expenditures and

despite the statements of the Prime Minister at the National Conference on Technology and Innovation in January 1988 about the importance of science and mathematics education in schools, the federal government's targeted expenditures on pre-college science and mathematics education are precisely \$0.¹¹

Dropout Rate

The dropout rate (estimated at between 25 and 30 per cent) in high schools drew attention to another set of issues that challenge the educational system. These issues include poverty, drug abuse, and alienation, and they prevent a growing number of students from participating fully in the education process. In Quebec, where the dropout rate was estimated at 36 per cent (1988-89), a policy paper released in the fall by the Quebec ministry of education identified poverty as the major obstacle to reducing the dropout rate¹² - a conclusion reached in several other studies elsewhere in recent years.

Furthermore, the dropout rate is a problem that is not easily resolved using standard educational solutions, e.g., longer class periods, imposition of tougher stay-in-school regulations, or even curriculum changes. The question then arises: who or what agency is responsible for providing a solution? This year the federal government introduced a new program, Start, aimed at supporting projects that offer solutions to the dropout issue. But Michel Pagé, Quebec's minister of education, is convinced this initiative is a waste of money:

We can do much more than the federal government with the money that will be spent on this program. Can anyone really say that Ottawa has the ability to define the local needs of people living in British Columbia or Quebec?¹³

In April, the Conference Board of Canada published its report on the dropout problem, *Profiles of Partnerships: Business-Education Partnerships that Enhance Student Retention*, and it also announced the establishment of the Conference Board's National Business and Education Centre. The report profiled 30 business-education partnerships currently operating that have enhanced student retention in schools across Canada through a variety of program strategies including dropout prevention and intervention. The report acknowledged that

because there is no one cause or common theme that explains dropping out, there need to be many programs and strategies to solve the many aspects of the problem.¹⁴

Universities and Community Colleges

EPF Transfers and Accountability

In a 1985 report on federal financing of post-secondary education and research prepared for the Secretary of State of Canada, A.W. Johnson reviewed the deficiencies in the finances (e.g., expenditures per student) and financing (e.g., federal and provincial contributions) of post-secondary education.¹⁵ He identified conflicting perspectives between the federal government and the provinces regarding the use of Established Programs Financing transfer payments. These payments represent the means by which the federal government contributes to the financing of universities and colleges. In particular, he reported that since the EPF transfers were unconditional, the provinces were not bound to spend the funds on universities and colleges. The federal government, on the other hand, believes that the provinces are morally bound to dedicate the fiscal transfers to postsecondary education without any offsetting decrease in provincial grants to universities and colleges. These issues reflect a long-standing debate over the provinces' wish for more fiscal autonomy and the federal government's wish for more accountability in the spending of federal funds.

A 1990 report prepared by James Cutt for the Institute for Research on Public Policy defined the issue of federal government funding for universities this way:

More difficult economic times required more careful choice in the use of scarce resources, and, in the absence of persuasive evidence of the value provided by the funds allocated to universities, governments turned to a more detailed framework of direct control.¹⁶

The federal government, in *Learning Well... Living Well*, was more oblique in expressing its desire for more accountability:

Investments in learning must be made in light of their long-term payoff to individuals, to companies and to society as a whole. Looking at spending on learning as an investment, rather than as an expenditure or a cost, changes the nature of some familiar discussions. It changes some of the questions we ask about learning.

For example, when looking at the amount of public funding going to education, the key

question is shifted from "which sector is underfunded?" to "which sector is providing the most benefits for moneys invested."¹⁷

In February 1991, the federal government extended, from the previous budget, its freeze on EPF transfer payments. The deep and lingering economic recession may have accounted for the freeze, but sceptics and pragmatists alike believe the reason had little to do with the recession. One suggestion is accountability. Since the federal government spends about \$11 billion a year on education and training in Canada, it wants more say on how its money is spent. A freeze puts pressure on provincial governments and provides the opportunity for the federal government to assess whether it is getting value for its investment.

Funding Options

In July, the Association of Universities and Colleges of Canada released a discussion document that examined options for funding university education and research. The report recognized that autonomy, whether for the universities and colleges or the provinces, does not imply a lack of accountability or responsiveness. In fact, the report stated:

To be considered seriously by the current federal government, new arrangements would have to be consistent with its emerging competitiveness/human resource development agenda, provide greater visibility and increased accountability... and avoid federal commitments to open-ended and formula-driven financing.¹⁸

The AUCC report stated that students and the private sector, as well as the federal and provincial governments, should contribute to the operation of universities and colleges. In the case of student support, the report qualifies its recommendation by stating that no student should be prevented from attending a postsecondary institution because of a lack of financial means. The report explored a number of direct-to-student funding mechanisms (e.g., vouchers, contingent repayment loans, and scholarships/bursaries) that would enable students to pay some portion of the cost of their education.

Without a countervailing increase in provincial funding, the freeze of EPF transfer payments had immediate effects on several campuses across Canada. Many universities and colleges experi-

enced overcrowding in classrooms, high student-professor ratios, and greater demands on resources such as computers, laboratory equipment, and library material. If this situation continues, and there is evidence that it will, there is concern that the quality of undergraduate and graduate programs will be compromised and so will Canada's ability to compete in a modern, global, economy. Over the last decade, the number of Canadian students enrolled in postsecondary education rose by 25 per cent, while real expenditures per student have been dropping since 1977 (with the exception of one year).¹⁹

Quality of University Education

In August 1990, the AUCC commissioned Stuart Smith, former chairman of the Science Council of Canada, to study the quality of university education. In the first few pages of the report, released in October 1991, Smith stated that Canada's university system is fundamentally healthy. Furthermore, he said that the economic squeeze felt by universities was being experienced by all sectors of the economy.²⁰ The report did not call for massive funding increases to universities but rather for gradual increases until funding matches the levels in U.S. state universities. He also suggested that tuition fees be increased gradually so that they cover 25 per cent of the university's operating costs. The report indicated that this latter action should not be taken until governments make student loans more widely available.

A principal conclusion of the Smith report, that teaching is undervalued at universities, exposed an increasingly contentious issue within the university community, namely its teaching versus its research function. According to Smith, "Universities don't like to see themselves as teaching institutions. They think teaching institutions are community colleges and high schools."²¹

Many factors have contributed to this situation, including changes in the structure of the federal government's university funding policies. The Smith report called for a new equilibrium between the teaching and the research function of universities. In order to redress this imbalance, the report suggested that each faculty member should be given the opportunity to choose whether performance would be evaluated primarily on the basis of teaching or research.

Enrolment of Engineers and Scientists

Although statistics indicate that the proportion of Canadians enrolled in universities is the second highest in the world,²² there are concerns about shortages in the labour market of certain professions, particularly in science, engineering, and technology. A number of reports have reiterated these concerns.²³ According to the Ontario Premier's Council report, *People and Skills in the New Global Economy*:

There have traditionally been two major sources of professionals and researchers in these fields: immigration and youth. During the 1960s, immigration supplied approximately half of the new engineers in Canada. By the mid-1980s, immigration was supplying less than a tenth of the new engineers.²⁴

Current information on the national supply of, and global demand for, scientists and engineers suggests, however, that neither strategy (immigration or youth) will be successful in meeting the growing demand in Canada. Other countries, including the United States, Sweden, Japan, and Britain are also forecasting shortages. This global shortage will likely result in increased competition for scientists and engineers. As for youth as a likely source to alleviate the bottleneck, enrolment in engineering and applied science has declined from 11 per cent of all university enrolments in 1980 to about 9 per cent in 1989-90, and enrolment in mathematics and physical sciences has declined to 5.5 per cent (1989-90) from a peak of 8 per cent in 1984.²⁵ The enrolment of women in math and physical sciences, however, is significantly up and their degree attainment in these fields has also risen significantly since 1975 (Table 1).

At present, there is no long-range or coordinated strategy to deal with the anticipated shortage of scientists and other highly qualified personnel. There are some direct initiatives such as the funding of scholarship programs. Through the federal government's Canada Scholarships Program (announced in 1988), \$80 million has been designated to support outstanding first-year students in science and engineering programs across the country. More funds for CSP were to be targeted as a result of the February 1991 budget. Indirect initiatives are mostly public awareness programs. The Council of Science and Technology Ministers announced the National Science and Technology Action Plan in May, which in-

cluded a program to enhance knowledge about, and interest in, scientific and technological careers among secondary school students. This program, Innovators in the Schools, joined other similar programs such as National Science and Technology Week and Science Culture Canada. Industry, including such firms as Du Pont Canada and General Electric Canada, have also become involved by contributing to the CSP and by participating in the Innovators in the Schools program. Whether these types of programs will meet labour market needs is at best uncertain.

Table 1. Women's Degree Attainment by Field of Study (Bachelor and First Professional University Degrees)

Field of study	Percentage of total earned by women	
	1975	1989
Household science	98.1	95.5
Nursing	97.0	96.0
Social work	68.2	77.9
Pharmacy	50.9	68.0
Physical sciences	16.1	23.0
Medicine	24.5	45.0
Engineering	1.8	11.5

Source: Industry, Science and Technology Canada, *Women in Science and Engineering: Vol.1: Universities* (Ottawa, 1991), 39-40.

There is some evidence to suggest, however, that the problem is more one of demand than supply. An industrial adjustment committee reported in July that the number of graduate chemists and chemical engineers working directly in their fields in 1988, two years after graduation (1986), was only 26 per cent and 17 per cent respectively.²⁶ So where are the other 74 per cent and 83 per cent of the graduates and what are they doing? According to the report, many are using their training to work in related occupations, such as university or secondary school teaching, medicine, and so on. Including these occupations raises the proportion of chemistry graduates working in their field to 60 per cent. Sixty-two per cent of graduates in chemical engineering are employed in some form of

engineering.²⁷ The report did not examine why graduates entered related professions or whether a shortage of industry-related jobs was an issue. The Chairman of the Science Council of Canada, Janet Halliwell, commented:

The assumption seems to be that Canadian demand for scientists and engineers will be that of an advanced industrial nation seized of the importance of innovation to economic strength and competitiveness. The evidence to the contrary is that the effective demand...is that of a semi-industrial nation.²⁸

Although it is important to ensure that a nation's educational system trains a highly qualified labour force, this effort must be matched by the creation of industries that can demand and absorb the production of skilled personnel.

Training

Towards Services

Over the last four or five decades the structure of the Canadian economy has changed enormously. Once based primarily on the production of goods (from the natural resource, manufacturing, and construction industries), it is now predominantly a service-producing economy based on transportation, communications, utilities, retail trade, and nonmarket services such as health, education, and social and public administration.²⁹ Today, over 70 per cent (up from 40 per cent in the 1940s) of Canada's workforce is employed in the service sector. Furthermore, the educational level of the workforce has risen with this shift and is expected to continue to rise over the next decade (Table 2).

Table 2. The Educational Requirements of Current Jobs in 1986 and of New Jobs in 1986-2000

Years of education and training	1986 Current jobs (%)	1986-2000 New jobs (%)
17 or more years	23	49
13 to 16 years	22	15
12 years (high school)	10	3
Less than 12 years	45	33

Source: Ontario Premier's Council, *People and Skills in the New Global Economy* (Toronto: Queen's Printer, 1990), 8.

Technological advances have also reshaped both the nature of Canada's economic engines and the make-up of the labour force. The implications of these changes have been widely studied by labour, industry, and provincial and federal government agencies including the Canadian Labour Market and Productivity Centre,³⁰ the Canadian Manufacturers' Association,³¹ the Ontario Premier's Council,³² and the Economic Council of Canada.³³ Their reports present evidence that illustrates the direct links between the level of educational attainment and income levels, the amount of training a person receives and labour productivity, and the degree of literacy and numeracy skills and employment opportunities.

Training Imperative

The OECD's *Employment Outlook* in July advocated "staying the course" on the new labour market policies it proposed in 1990. These policies set out a number of long-term objectives that gave priority to active labour market measures including training, placement, and rehabilitation programs for the unemployed; development of employment-related skills to avoid skill gaps; more effective matching of people to jobs; and encouraging active job searches. The report suggested that Canada's unemployment rate (high by historic and international standards) is in part the result of its inefficient unemployment insurance schemes, high minimum wages, and inadequate training programs. More generous insurance in high-unemployment provinces has reduced the incentive for the jobless to search for a job in another province (or another sector). The report also stated that increases in Canada's unemployment and unfilled job vacancies in recent years are indicative of structural unemployment problems. These problems arise when the skills that the unemployed possess are no longer useful in the evolving labour market.

Better training has become a central component of prescriptions for economic recovery and competitiveness. For instance, Cedric Ritchie, chairman of the Bank of Nova Scotia, has suggested, "We need a national commitment to competitiveness that begins on the shop floor and extends to the highest councils of business, labour and government."³⁴

Peter Larson, co-author of the Conference Board of Canada's report on training and development, pointed to the need to spend more on training employees:

It really is becoming clear that companies stand or stumble largely on their human assets.... All this talk about "people are our most important asset" was for a long time vacuous. Now there is some evidence companies are beginning to believe it.³⁵

William Waite, president of Siemens Electric Ltd. of Mississauga, says, "My problem is not the 88-cent dollar; my problem is skilled labour."³⁶ Siemens, the German electronics firm, wants to quadruple its current workforce of 3000 people in Canada, but a shortage of skilled labour may curtail those plans.

The fact that rhetoric has far outdistanced action on Canadian education and training issues was underlined by the Human Resource Development Committee of the National Advisory Board on Science and Technology in its April 1991 report *Learning to Win: Education, Training and National Prosperity*. This committee of NABST, which is chaired by the Prime Minister, noted that over the past 10 years there have been 40 reports containing 600 recommendations about Canadian education and training, but that these have had "only minor discernible effects."³⁷

Part of the answer must be that Canadians, although uneasy about the quality and relevance of education, are reasonably satisfied with the status quo. Yet the Canadian economy has not paid its way since the mid-1970s, and among those who know or will admit this, education and training are identified as the principal tools with which to redress the situation.

The only conclusion is that the message of economic crisis has not got out. Not nearly enough people understand (or want to understand) its long-term implications. For years we have allowed constitutional, legal and political wrangling to dominate the news and absorb political energy, leaving the economy and the environment to fend for themselves.³⁸

The NABST report acknowledged, however, that there are "massive problems of jurisdiction and entrenched self-interest" and that "deficit reduction must remain the overall first priority."³⁹ Funding, according to the report, will have to come from reallocating existing government expenditures and investments by the private sector.

Policy Initiatives

The NABST conclusion – no new money for education and training – is consistent with the recommendation made in the 1989 report of the Advisory Council on Adjustment, the agency created by the federal government to examine the ramifications of the Canada-U.S. Free Trade Agreement. Its report indicated that Canada spends as much as Germany, Sweden, and Finland, as a percentage of GDP, on labour market programs, including income maintenance (unemployment insurance benefits) and employment promotion programs (e.g., Canadian Job Strategy).⁴⁰ The difference, however, is that countries such as Japan, Sweden, Germany, and Britain spend relatively more on employment promotion and less on income maintenance (Table 3). The report saw “little need to recommend a dramatic increase in overall levels of moneys [for labour-market intervention]” and suggested a shift in emphasis towards employment promotion programs.⁴¹ Its other recommendations in this area included doubling the amount allocated to training programs and increasing the funding for skill-shortage and skill-investment programs.

Table 3. Government Employment Promotion and Income Maintenance Expenditures as a Percentage of Total Labour Market Expenditure, 1987

	Employment promotion measures	Income maintenance measures
Sweden	70	30
West Germany	42	58
United States	29	71
United Kingdom	35	65
Finland	32	68
Japan	29	71
Canada	25	75
France	24	76
Australia	21	79

Source: Advisory Council on Adjustment, *Adjusting to Win* (Ottawa: Supply and Services Canada, 1989), 46.

The federal government has responded to some of the suggestions made by the Advisory Council on Adjustment by shifting its training focus over the past couple of years from passive unemployment insurance income support to entry-level skills training and cooperative education. This shift was made principally through the Canadian Job Strategy programs and unemployment insurance reforms. In April 1989, Ottawa announced a new initiative (under the Canadian Job Strategy), the Labour Force Development Strategy, to support active training programs for youth. This initiative was broadened recently to include adults.

In January 1991 the government announced a new Canadian Labour Force Development Board, a mix of business, labour, education, and social action representatives. Co-chaired by Laurent Thibault (former chairman of the Canadian Manufacturers' Association) and Gérard Docquier (former national director of the United Steelworkers of America, Canadian Branch), the board is charged with advising and recommending on more, better, and more accessible training. More importantly, the establishment of the CLFDB is an attempt to engage industry more actively and effectively in human resource development. In Ontario, a similar initiative (the Ontario Training and Adjustment Board) was to be announced.

In April, the Canadian Manufacturers' Association announced a Canada-wide management training program that will be marketed and sold to small and to medium-sized businesses. Unlike other training programs, which are brought in from other countries, this program, *Compete to Win*, was developed within Canada with the involvement of the private sector, government, the academic community, and union and non-union employees. It was funded (\$1.8 million) by Employment and Immigration Canada.

Too Many Free-Riders

The Economic Council's 1991 report *Employment in the Service Economy* points out that only 31 per cent of private sector firms supported or directly provided formal training for their employees in 1987 and notes that there is no evidence to suggest this has changed since. Moreover, there is a strong disincentive to change because some firms who do not invest in training poach from firms that do – “free-riding,” as the Council calls it.⁴²

Periods of economic recession also contribute to the problem of under-investment in human resources because companies are less likely to spend on training in hard times. Furthermore, training, when it takes place, is generally confined to industries whose employees already have a high level of educational attainment, leaving employees in other industries such as manufacturing, mining, fishing, and forestry in a training vacuum.⁴³

A 1990 report by the Hudson Institute, *Workforce Literacy: An Economic Challenge for Canada*, suggests that one of the principal causes of inadequate skills in the workforce is the absence of a strong tradition of training among Canadian businesses.⁴⁴ Policy proposals, such as a training tax, have been suggested to eliminate the advantages of free-riding and to create incentives to provide training.

Beyond Job Skills

An increase in task-specific job skills training is only one step in the process that confers competitive advantage. Nan Stone, citing the findings of the Commission on the Skills of the American Workforce, revealed that:

...researchers expected employers to report widespread skills shortages and that new jobs would require higher skills. Instead, they found limited skills shortages and a tiny minority of companies...that were concerned about their growing need for better educated workers.... The skills more than 80% of employers worried about were not academic but social - good work ethic, a pleasant demeanour, reliability.⁴⁵

For M.J. Ryan, president of Ryka Blow Molds Ltd., Mississauga, the current approach to skills training lacks certain elements such as the development of sound work habits, pride, awareness of change and the effect on the individual, and an understanding of the employer's position of competition in a global market, as well as sound generic and technical skills.⁴⁶ Generally, more attention needs to be devoted to the discussion of non-skills-related training and education.

Also affecting competitiveness are management skills and employee-management relations. Although some industry representatives have heavily criticized the education and skill levels of Canadian employees compared to those of Japanese or German workers, there is no evidence to

suggest that Canadian workers would not be as productive under the right kind of management. In fact, says Charles McMillan, management professor at York University:

The Japanese [in their Toyota plant in Alliston, Ontario] have taken Canadian workers and turned out products that are the equal of anything in Japan. It proves that employee-management relations are a fundamental issue.⁴⁷

Michael Porter, the Harvard business professor hired to diagnose Canada's competitiveness, also pointed to the poor performance of Canadian managers as one of the factors contributing to Canada's poor economic performance.⁴⁸

Towards National Standards

To ensure that worker training is of the highest quality and that the acquired skills are portable from one province to another, national training standards were advocated last year by many task forces and committees.⁴⁹ For its part the federal government, in proposing (as mentioned above) a constitutional amendment to place labour market training under exclusive provincial jurisdiction, also called for joint federal-provincial leadership in establishing skills standards.⁵⁰ Whether the discussion on national standards can generate action over the next few years is uncertain, considering the issues raised in federal-provincial relations.

Literacy

Once considered a problem for developing countries, literacy now also concerns the developed countries, who have come to recognize its crucial role in economic growth and development. The common assumption about illiteracy - that it is a problem for a few unemployed and marginalized youth - does not hold up in analysis.⁵¹ The assumption was also refuted in the report of the Conference Board of Canada on the impact of employee illiteracy on Canadian businesses. Fully 70 per cent of the 626 companies surveyed by the Board indicated that they had a significant problem with functional illiteracy in some part of their organization.⁵²

The figure most often cited for functional illiteracy in Canada, 38 per cent, is derived from a 1989 Statistics Canada survey of the "Literacy Skills Used in Daily Activities" by adult Canadians between the ages of 16 and 69 (Table 4). It represents the proportion of Canadians who have

reading limitations that potentially affect their daily and working life – not those who can neither read nor write their own name (the illiterate). The survey further indicated that 16 per cent of adults have reading skills too limited to deal with written material that they encounter every day, while 14 per cent have limited numeracy skills.⁵³ The study also revealed that proficiency in literacy and numeracy skills diminishes with age and increases with educational attainment, and that literacy rates tend to decline steadily from west to east. These latter findings confirm the results of a 1987 survey on adult literacy conducted for Southam News.

Table 4. Percentage of Canadians Aged 16-69 Whose Reading Skills Meet Most Everyday Demands (Reading Level 4)

Province	%
Saskatchewan	72
Alberta	71
British Columbia	69
Manitoba	65
Ontario	62
Quebec	57
Nova Scotia	57
New Brunswick	56
Newfoundland	39

Source: Statistics Canada, *Adult Literacy in Canada: Results of a National Study*, cat. no. 89-523E (Ottawa, 1991), 27.

A Cost to Everyone

For industry, functional illiteracy means lost productivity, literacy-related accidents and safety costs, and additional costs for basic remedial training. One estimate of the cost of functional illiteracy to industry is \$4.2 billion a year.⁵⁴

For Canadians in general, functional illiteracy places greater demands on social safety nets, which in turn lead to higher taxes to finance these programs. The Canadian Business Task Force on Literacy estimated that the cost of illiteracy to Canadian society exceeds \$10 billion a year.⁵⁵ Furthermore, illiteracy creates barriers to training that prevent individuals from participating in the rapidly changing labour market and from receiving the benefits of working in higher-paying jobs.

The traditional response of industry to reports on literacy rates has been to blame schools for falling educational standards. However, improving schools will not address the literacy needs of the current labour force: about two-thirds of individuals who will be in the labour force in the year 2005 are already working. The OECD's report, *The Literate Worker*, suggests that, although there is strong support for fighting illiteracy, employers do not match their rhetoric with significant investment. While it is true that some companies such as SCRL Electric Ltée (Quebec), Budd Canada Inc. (Ontario), Fishery Products International Ltd. (Newfoundland), and BP Canada (Alberta) have invested in literacy training for their employees, many more have not. The Conference Board of Canada reported that only 24 per cent of the firms it surveyed had developed a systematic human resource policy or program to deal with the issue of workforce illiteracy.⁵⁶

Illiteracy in the workforce is matched by a high rate of illiteracy among students. The Canadian Teachers' Federation and the federal government's National Literacy Secretariat reported in October that 3 out of 10 students have some difficulty with reading, writing, and math.⁵⁷ Poverty prevents many students from coming to school ready to learn, their study found. Teachers they surveyed identified poor home environments (poor nutrition, abuse), as well as learning disabilities and cultural and language differences, as factors contributing to the problem. Harvey Weiner, deputy secretary-general of the Canadian Teachers' Federation, disputes the notion that schools are not doing their job:

The only way we're going to reduce the scope of the literacy problem is to recognize that it is a societal problem, which will only be resolved if we get all segments [of society] doing their share of the job.⁵⁸

Where's the Action?

In 1988 the federal government acknowledged that it had sat on the sidelines and left the issue of illiteracy to the efforts of the voluntary sector.⁵⁹ Over the years, it has made funds available to provincial government and non-government agencies for the delivery of a variety of literacy programs. These programs, numbering in the thousands, have served an important function in society. Yet the need for literacy has evolved from being an element of social necessity to an element

of economic necessity as well. The question then arises: Are current literacy training programs meeting the needs of present and future labour markets as well as social needs? The answer, according to the OECD report on literacy, is that very little research and analysis has been done on what kinds of remedial programs succeed in improving adult literacy. Jean-Paul Hauteceur, a literacy consultant, concurs with this assessment and suggests that more program-based research is required for literacy training programs if they are to be effective in achieving their objectives.⁶⁰ In the meantime, experience so far suggests that

basic skills may most effectively be acquired in the context in which they will be used – that is, where the purpose is to improve performance at work, literacy may most easily be acquired in programmes based in the workplace.⁶¹

In *Learning Well...Living Well* the federal government suggested that a possible end-of-decade target would be to cut the rate of adult illiteracy by half. Other than suggesting that everyone has a part to play in meeting this objective, the document offers no fiscal or policy changes to facilitate this action. What the federal government has done is to shift the National Literacy Secretariat from the auspices of the Secretary of State to the Ministry of Multiculturalism and Citizenship. No policy rationale was offered to explain the shift.

The general lack of action by government and industry on improving literacy reflects the attitudes most Canadians have about the issue. In a 1990 Decima poll conducted on behalf of ABC Canada, a non-profit organization established by the private sector to promote literacy, Canadians viewed illiteracy as more of a social problem (46 per cent) than either an educational (26 per cent) or an economic issue (10 per cent).⁶² The survey also revealed that most people think that public schools (31 per cent), federal (22 per cent) and provincial (30 per cent) governments, as well as the individuals themselves (50 per cent), are most responsible for assisting adults with the problem of illiteracy. (Respondents could choose more than one response.) Only 13 per cent of respondents thought employers had any role to play in literacy development.

Conclusion

It is too early to assess whether the findings of the various task forces, committees, and research surveys regarding the importance of education, training, and literacy for Canada's economic and social development have made a significant impression on any sector of the Canadian economy. Perhaps what the NABST committee found is still true: "the message of economic crisis has not got out." Michael Porter's report suggests that Canadian public indifference is a condition brought on by "paternalistic government policies, a history of market protection and accumulated attitudes and experiences of both individuals and businesses." *The Economist* of 29 June 1991 suggested that Canadians' "fondness for government" (to solve their problems) prevents substantial change from occurring.

To date, most of the federal government's initiatives to produce change in Canada's education, training, and literacy policies have been oriented towards developing nationwide goals and abstractions such as "learning cultures" or public awareness programs. The underlying assumption directing these efforts is that a change in individual and collective attitudes will result in changes in individual and collective behaviour. There is not much evidence that these types of programs or strategies work.

Neither is there evidence to suggest that Canada is any less equipped or trained to define and solve problems than any other country. The number of Canadians with postsecondary diplomas and degrees rose from 21.6 per cent in 1985 to 25 per cent in 1989.⁶³ Canada's enrolment rate in postsecondary education is the second highest of 17 OECD countries.⁶⁴ The same *World Competitiveness Report* cited earlier ranked Canada second in higher education enrolment, and fourth in secondary school attainment and quality of its labour force. Why, then, have the nation's industries and public institutions not harnessed these skills and knowledge and made more effective use of this tremendous natural resource? Perhaps it has been for the same reasons that industry and government have failed to add value to Canada's other natural resources – its trees, fish, land, and water. Until some answers can be found to this fundamental question, the educational, training, or literacy solutions offered to revitalize Canada's economy will be viewed, at best, as tinkering.

Notes

1. Organisation for Economic Co-operation and Development, *Employment Outlook 1991* (Paris, 1991), ix.
2. "Can standardized tests make the grade?" *The Toronto Star*, 21 September 1991, D4.
3. Jennifer Lewington, "The blackboard dilemma," *The Globe and Mail*, 31 August 1991, D1.
4. Lila Sarick, "To test or not to test: that is the question," *The Globe and Mail*, 14 May 1991, A1.
5. Jennifer Lewington, "Diploma tests ticket to the 'real world'," *The Globe and Mail*, 15 October 1991, A9.
6. Drew Fagan, "Ottawa to take economic plan on road," *The Globe and Mail*, 30 October 1991, A1, 9.
7. Stuart L. Smith, *Report: Commission of Inquiry on Canadian University Education* (Ottawa: Association of Universities and Colleges of Canada, 1991), 124.
8. Economic Council of Canada, *Employment in the Service Economy* (Ottawa: Supply and Services Canada, 1991), 163.
9. Canada, *Canada Must Compete*, report of the Standing Committee on Industry, Science and Technology, Regional and Northern Development, Barbara J. Sparrow, chairman (Ottawa, 1990), 7-8.
10. Government response to *Canada Must Compete*, report of the Standing Committee on Industry, Science and Technology, Regional and Northern Development, House of Commons, Sessional Paper 343-8R/22, 13 May 1991.
11. Graham Orpwood, *L'enseignement des sciences et des mathématiques en Amérique du Nord: En progrès ou en déclin?* (Québec: Conseil de la science et de la technologie, 1990), 67.
12. Rhéal Séguin, "Quebec vows to cut school dropout rate," *The Globe and Mail*, 11 September 1991, A1, 7.
13. *Ibid.*
14. Michael Bloom, *Profiles of Partnerships: Business-Education Partnerships that Enhance Student Retention* (Ottawa: Conference Board of Canada, 1991), 2.
15. A.W. Johnson, *Giving Greater Point and Purpose to the Federal Financing of Post-Secondary Education and Research in Canada*, report prepared for the Secretary of State of Canada (Ottawa, 1985), vi.
16. James Cutt, *Universities and Government: A Framework for Accountability*, report for the "Workshop on Canadian Universities: Problems and Opportunities in the 1990's," Ottawa, 2-3 November 1990, vii.
17. Prosperity Secretariat, *Learning Well...Living Well* (Ottawa: Minister of Supply and Services, 1991), 18.
18. Association of Universities and Colleges of Canada, *An overview of selected options for funding university education and research* (Ottawa, 1991), v.
19. A.W. Johnson, *op. cit.* (note 15), v.
20. Peter Hum, "Make teaching first priority, commission report urges," *The Ottawa Citizen*, 10 October 1991.
21. Lynne Ainsworth, "Teaching second to research university commission finds," *The Toronto Star*, 10 October 1991, A4.
22. "Review of education and training in Canada," *Quarterly Labour Market and Productivity Review* (Spring 1989): 19-29.
23. Thomas E. Clarke and Jean Reavley, *Educating Technological Innovators and Technical Entrepreneurs at Canadian Universities*, discussion paper (Ottawa: Science Council of Canada, 1987); Ministry of State for Science and Technology, *University Research in Canada*, background paper for the National Forum on Post-Secondary Education (Ottawa, 1987); Natural Sciences and Engineering Research Council of Canada, *Canada's Future Requirements for Highly Qualified Scientists and Engineers* (Ottawa, 1989).
24. Ontario, *People and Skills in the New Global Economy*, Premier's Council Report (Toronto: Queen's Printer, 1990), 73.
25. Judith Maxwell, chairman of the Economic Council of Canada, speech to the National Forum of Science and Technology Advisory Councils, Victoria, 30 September 1991.
26. *The Chemical Professions in Canada: Employment and Education for the Future*, report of the Industrial Adjustment Committee on the Supply and Demand of Chemical Professionals in Canada, Graham Orpwood, chairman (Ottawa: Chemical Institute of Canada, 1991), 14-15.
27. *Ibid.*
28. Janet E. Halliwell, chairman of the Science Council of Canada, "Problem or Paradox? Resources for R&D," notes from an address to the Canadian Research Management Association, Ottawa, 23 September 1991.
29. John N.H. Britton and James M. Gilmour, *The Weakest Link: A Technological Perspective on Canadian Industrial Underdevelopment*, Science Council of Canada, Background Study 43 (Ottawa: Supply and Services Canada, 1978).
30. Canadian Labour Market and Productivity Centre, *Labour Force Development Strategy* (Ottawa, 1990).
31. Canadian Manufacturers' Association, *The Aggressive Economy: Daring to Compete* (Toronto, 1989).
32. Ontario, *op. cit.* (note 24).
33. Economic Council of Canada, *op. cit.* (note 8).
34. D. Crane, "Ottawa must help business get competitive, banker says," *The Toronto Star*, 30 April 1990, B1, 5.
35. M. Gibb-Clark, "Report applauds training costs: Profits, recruitment boost cited," *The Globe and Mail*, 19 April 1991, B1, 6.
36. D. Crane, "Siemens aims to add 9,000 jobs: Plan depends on supply of skilled workers," *The Toronto Star*, 20 September 1991, C1, 5.
37. National Advisory Board on Science and Technology, *Learning to Win: Education, Training and National Prosperity*, report of the Human Resource Development Committee to the Prime Minister of Canada (Ottawa, 1991), i.

38. Ibid.
39. Ibid., letter of submission and p. 30.
40. Advisory Council on Adjustment, *Adjusting to Win* (Ottawa: Supply and Services Canada, 1989), 171.
41. Ibid., 48.
42. Economic Council of Canada, op. cit. (note 8), 127.
43. Peter Larson and Matthew W. Blue, *Training and Development 1990: Expenditures and Policy* (Ottawa: Conference Board of Canada, 1991); Industry, Science and Technology Canada, *Human Resource Profile of the Canadian Fish Processing Industry* (Ottawa: Supply and Services Canada, 1991); Statistics Canada, *Human Resource Training and Development Survey* (Ottawa: Information Canada, 1987).
44. Marie-Josée Drouin, *Workforce Literacy: An Economic Challenge for Canada* (Montréal: Hudson Institute of Canada, 1990), 96.
45. Nan Stone, "Does Business Have any Business in Education?" *Harvard Business Review* (March-April 1991): 52.
46. Christopher Trump, "Our students compete with best," *The Financial Post*, 20 December 1990, 14.
47. Brenda Dalglish, "A failing grade," *Maclean's* (28 October 1991): 38.
48. Michael E. Porter and the Monitor Company, *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Business Council on National Issues and Supply and Services Canada, 1991).
49. CLMPC, op. cit. (note 30); Prosperity Secretariat, op. cit. (note 17); NABST, op. cit. (note 37); Advisory Council on Adjustment, op. cit. (note 40).
50. Canada, *Shaping Canada's Future Together: Proposals* (Ottawa: Supply and Services Canada, 1991), 34.
51. Lauren Benton and Thierry Noyelle, *The Literate Worker: Adult Literacy and Economic Performance in Industrialised Nations*, Organisation for Economic Co-operation and Development, forthcoming.
52. Robert C. DesLauriers, *The Impact of Employee Illiteracy on Canadian Business* (Ottawa: Conference Board of Canada, 1990), 11.
53. Gilles Montigny and Stan Jones, "Overview of literacy skills in Canada," *Perspectives* (Winter 1990): 32-40.
54. Canadian Business Task Force on Literacy, *Measuring the Costs of Illiteracy in Canada* (Toronto, 1988), 7.
55. Ibid.
56. Robert C. DesLauriers, op. cit. (note 52), 8.
57. Jennifer Lewington, "Illiteracy impedes 30%, survey says," *The Globe and Mail*, 29 October 1991, A3.
58. Ibid.
59. The Honourable Brian Mulroney, Prime Minister of Canada, notes for an address on literacy, Toronto, 8 September 1988, released from the Office of the Prime Minister.
60. Jean-Paul Hauteceur, *Program-based Research in Literacy*, National Literacy Secretariat (Ottawa: Multiculturalism and Citizenship Canada, 1991), 28.
61. Donald Hirsch, "Overcoming Adult Illiteracy," *OECD Observer* 171 (1991): 23.
62. ABC Canada, *Attitudes of Canadians toward the issue of literacy* (Toronto, 1990).
63. *The Globe and Mail*, 12 September 1991, A5.
64. "Review of education and training in Canada," op. cit. (note 22), 23.

2. Industrial Innovation and Technology*

Globalization and Innovation

Many Canadians would support the view of the Canadian Research Management Association:

The forging of R&D linkages to enhance industrial innovation is particularly important to Canada, given that its technological resources are limited, and that its industries must employ technology if they are to remain competitive in the global marketplace.¹

It is a perspective shared by many readers of the Science Council's newsletter, *In Touch*: responses to a questionnaire included with the July 1991 issue of *In Touch* revealed broad agreement that industrial innovation and technology are fundamental to economic revival. As one reader put it,

Industrial technology and innovation is a disaster zone for Canada. If we fail to improve industrial technology and innovation, then all other issues become irrelevant, and so, alas, does the country.

The challenges of globalization, competitiveness, structural change and adjustment, and the reconfiguration of the federation and its governing institutions will all have a profound impact on how the Canadian economy and society evolve. Advances in communications (particularly satellite technology, broad-band networks, and closely linked financial networks) as well as advances in transportation have permitted the building of powerful economic trading blocs. These are forcing companies to approach markets from a global perspective that is also sensitive to local customer needs.

Increasingly, escalating costs are forcing firms to penetrate international markets. Domestic markets are no longer sufficient to generate the revenues needed to support high product-development costs in areas such as microelectronics, new materials, biotechnology, and pharmaceuticals. They are also not large enough for the traditional resource and goods-producing sectors. Numerous studies over the past several years have driven home the same fundamental point: to compete, Canadian firms must innovate.

*This chapter describes the major events and directions in industrial innovation and technology in Canada in 1991, building on the themes of Part 2 of this report, "Competing through Innovation."

To innovate, Canadian management must accept the new definition of competitiveness described in Part 2 of this report. The challenge is not simply to invest more in R&D, but to improve management, quality control, marketing, and intelligence gathering as well as achieve a judicious "bundling" of these. As Paul Cook, chief executive officer of Raychem, has put it,

Every company is innovative or else it isn't successful. It's just a question of degree. The essence of innovation is discovering what your organization is uniquely good at – what special capabilities you possess – and taking advantage of those capabilities to build products or deliver services that are better than anyone else's. Every company has unique strengths. Success comes from leveraging those strengths in the market.²

In Canada, a consensus is emerging in business, government, financial, labour, and academic circles that the lack of industrial innovation is retarding Canada's ability to adapt quickly to change. Analyses over the past year by the Science Council of Canada, Michael Porter, Richard Lipsey, Alan Rugman and Joseph D'Cruz, Coopers Lybrand, the Economic Council of Canada, the Canadian Labour Market and Productivity Centre, and others have all pointed to this deficiency.

The Science Council's current examination of the technology strategies of leading sectors points to a series of lacunae in our industrial structure – deficiencies that account for much of Canada's relatively low spending on private sector R&D. Problems include the dependence on a resource-based economy, the high proportion of small and medium-sized businesses, significant foreign ownership of our manufacturing economy, and the weak equipment and machinery industries. Some commentators see the absence of a large defence program as a further handicap to Canadian industrial innovation, but the argument is weakened by similar circumstances in Japan and Germany.

Another telling factor in Canada's poor innovation record is the general failure of management in all respects. As Cedric Ritchie, chairman and chief executive officer of the Bank of Nova Scotia, points out,

The challenge is to instill habits of innovation, continuous product and process improvement, and the relentless upgrading of technology, even in the most basic resource industries. Ask yourself, for example, why we Canadians had to wait for the Norwegians to teach us how to farm salmon.³

The availability of capital, particularly risk or venture capital, also poses problems for our innovative capabilities. Some argue that Canada's risk capital for technology-based start-ups is non-existent. Others say there is plenty of money around – that what is lacking are good projects and an understanding by venture capitalists of technology-based projects.⁴

Protection of intellectual property is clearly critical in a borderless world, where investments in R&D can sink or swim on the basis of how proprietary information is protected. The pharmaceutical industry is a good example of how poor intellectual property guidelines have acted as barriers to investment in this country, and where, as some have argued, Canada is disadvantaged because its patent protection has been weaker than that of global competitors.⁵

And, of course, there is the question of a skilled workforce. Interviewed in Ottawa on 8 July 1991, Robert Reich of Harvard University suggested,

There are only two ways in which a government can attract global capital to its country. One way is saying come here because it is so cheap to do business here.... The other way of attracting global capital, global corporations to Canada...is saying come here because we have a first-class workforce and a first-class infrastructure, and our human capital and infrastructure combined with your know-how and financial capital will generate huge returns.⁶

Canada's natural resources sector, historically the country's major international trading asset, is experiencing decreasing profit margins. The real prices of Canada's export commodities have been gradually declining for at least the last 15 years as new competitors enter international markets and substitute materials are found. For example, the Canadian metals price index fell from 119.5 in 1965 to 109.6 in 1990.⁷

Traditionally, Canada has adopted and adapted technology developed elsewhere to extract natural resources. These resources were then exported with little value added. This approach to economic development was adequate for the

times and a high level of productivity sustained a high-wage economy. However, the growth of Canadian productivity is declining. Annual productivity growth, which was 2.3 per cent between 1946 and 1973, fell to 0.9 per cent between 1973 and 1990. Hence, Canada's international competitiveness has been faltering, and has declined particularly sharply vis-à-vis the United States.

In the fall of 1991 the federal government began a consultative process by releasing the discussion paper *Prosperity through Competitiveness*. The government, through a private sector steering committee, has invited discussion on what it calls the five building blocks of Canadian competitiveness: learning and education, new technologies, finance and investment, a competitive domestic market, and improved international trade.

Canadians have been debating these issues for several decades now, and exercises such as this new one often evoke a certain cynicism and sense of déjà vu in the private sector, which for the past two decades has been arguing for a stable economic policy and coherent framework policies to create the environment necessary for wealth creation. In the meantime, the global context for competition has changed considerably.

Private Sector Initiatives: Facing International Competition

The Competitiveness Issue

Canada's debate on international competitiveness took on new intensity and focus in 1991 with the publication of Michael Porter's *Canada at the Crossroads: The Reality of a New Competitive Environment*.⁸ Porter argues for a new paradigm for economic development in Canada based on innovation.

Interestingly, Porter identifies semiconductors and computers as upstream or commodity sectors (along with minerals and forestry) in the new world economy, because they are the "raw material" for advanced informatics and communications products. Of course, in Canada, while we have substantial surpluses in the traditional raw materials sectors, we have a deficit in semiconductors, one of the building blocks of value-added industries in a new economy based increasingly on "grey matter" industries.

By giving a commodity aspect to what are conventionally accepted as advanced sectors,

Porter clearly indicates the direction that industrial innovation needs to take. A dedicated thrust to capture niches in "grey matter" sectors, such as telecommunications where Canada has strengths, would lead to a more balanced trade picture.

Earlier in the year, Kodak Canada Inc. released a study on Canada's competitiveness prepared by Alan Rugman and Joseph D'Cruz of the University of Toronto.⁹ These authors argued that a full understanding of Canadian international competitiveness requires analysis of the issues within a North American context, and not simply the domestic perspective offered by Porter. It is only through an understanding of the close industrial links between Canada and the United States, they said, that competitive conditions in Canada can be appreciated.

The Economist's 1991 "Survey of Canada" listed a number of factors that were perceived to affect Canada's competitiveness.¹⁰ These included high interest rates, high taxes, regulations, and interprovincial trade barriers. In particular, the survey emphasized the reluctance of Canadian firms to embrace new technology and to spend money on R&D; it also pointed to a general lack of inventiveness.

Some of the issues pertaining to industrial innovation and competitiveness were picked up in other reports. For example, the Prime Minister's National Advisory Board on Science and Technology issued two reports, one on the financing of industrial innovation and the other on human resource development.¹¹

The first report made the following recommendations regarding the financing of industrial innovation:

- a new capital gains exemption on eligible equities held for more than three years;
- a modest levy on pension funds that fail to invest in small R&D-intensive enterprises or in risk capital groups that target technology ventures;
- an industrial innovation risk-sharing fund of up to \$1 billion managed at arm's length from government;
- a \$100 million matching fund that would top up venture equity investment secured by start-up or early-stage technology enterprises;
- an industrial innovation merchant bank to supply both equity and debt financing for technology-intensive firms.

Most of these recommendations have fallen on deaf ears. However, some dynamic and innovative experiments have been initiated independently in Quebec. For example, in March 1992 Quebec plans to implement a new policy aimed at making the financial community more aware of the fact that firms must make long-term investments in training, new technology, and research. As a result of the policy, Quebec's chartered accountants will follow a new system to help small and medium-sized firms frame their long-term goals. They will examine investments by SMEs in areas such as training and research and development, and include the information in the companies' financial statements. As a result, bankers and investors will have a more appropriate explanation of any financial setbacks caused by such investments. Further, the Quebec government is insisting that these new financial statements, which incorporate long-term considerations, be provided for any SMEs seeking loans from the public purse.

The second NABST report focused on the need for life-long education and training, arguing that these are necessary if people are to possess the skills that will enable them to participate effectively in the industrial innovation process. The government's Prosperity Initiative took up this argument in the discussion paper *Learning Well...Living Well*.¹² The issue is a global one now being debated in most industrialized economies. As *The Economist* pointed out:

Technologies pass rapidly from one company to another. Only that intangible, vital quality, the environment of active brains and productive skills in which companies operate, is non-transferable. To change it, governments need to start at the school-gate.¹³

(We explore the education agenda further in the "Education, Training, and Literacy" chapter.)

The views of the high technology community were captured in a 1991 pre-budget submission by the Canadian Advanced Technology Association. That submission placed the promotion of competitiveness and structural adjustment as the first priority of government and proposed the following goal:

Canada must shift a higher percentage of national investment into the production and marketing of advanced technology goods and services, into the production of higher value-added products in all sectors, into the

application and use of technology to build competitiveness, and into the development of human resource capability required to facilitate these shifts.

Industrial R&D

A key indicator of industrial innovation is industry's commitment to R&D. Statistics Canada has estimated that the total corporate R&D outlay will increase by 5.9 per cent in 1991 to more than \$5.2 billion. This compares to a 5.6 per cent increase in 1990 and a 2.7 per cent rise in 1989. As we note in the "Infrastructures" chapter, industry's expenditures on R&D have risen dramatically since 1977, partly as a result of the introduction of industrial R&D support programs and tax incentives for R&D. There are now over 3300 companies performing R&D; 25 of these account for half of all industrial R&D in the country.¹⁴

The telecommunications sector is the largest performer of intramural R&D. It is followed by aerospace, engineering and scientific services, business machines, other electronics, computer and related services, electrical utilities, pharmaceuticals, other chemicals, and refined hydrocarbons. The first six sectors account for more than half of all intramural R&D expenditures. This concentration of R&D spending has not changed perceptibly since 1973.¹⁵

Telecommunications R&D deserves special mention since it clearly outdistances that done by other technology-intensive sectors and accounts for the largest share (about 17 per cent) of Canadian industrial R&D. Most of this R&D can be attributed to Northern Telecom Ltd., Canada's world-scale telecommunications company, which is pushing into new areas such as optoelectronics. Canadian telecommunications firms are also pursuing R&D in areas such as private branch exchanges, mobile communications, satellite communications, data switching, transmission equipment, and microelectronics.

Aerospace, the next most R&D-intensive sector, has a number of niche products including Canadair's executive and regional jets as well as CAE's flight simulators. David Race, chief executive officer of CAE, sees R&D as a necessity in this sector: "Without research and development, you don't get the quality, the products, or the prices you need in order to compete."¹⁶ In space-related R&D, Canadian companies are most active in communications satellites, remote-sensing satellite systems, and space robotics. Recent prelimi-

nary analyses of the balance of trade show that aerospace jumped from a deficit of \$1.6 billion in 1988 to a surplus of \$975 000 in 1990.¹⁷

There has been a major increase in R&D spending by the pharmaceutical sector, largely due to the passage in 1987 of Bill C-22, which improved patent protection on new drugs. Amendments to the bill included the requirement that the Canadian pharmaceutical industry double its ratio of R&D to sales by the end of 1996 (from 5 to 10 per cent). By 1990, this ratio had climbed to 8.8 per cent with total expenditures amounting to \$281 million. While much of this went to applied research in industrial development facilities, a significant amount went to basic research in universities and hospitals.¹⁸

R&D expenditures decreased in some areas, notably the electrical products and automotive sectors. In these and a number of other sectors, investments by Canadian business are well behind those of international competitors. As the results from the Science Council's sectoral technology strategy study indicate, much of the Canadian economy has chosen to compete on the basis of cost, rather than innovation and quality.

Sectoral Strategies

Sectoral strategies have become highly favoured levers for governments to promote and strengthen industrial innovation. Quebec, for example, has announced an economic development strategy that focuses on 13 industrial clusters, all of which have a strong knowledge component. As Gérald Tremblay, Quebec's minister of Industry, Commerce and Technology argues,

our collective success now rests on the rapid transition from an economy based on mass production to one based on value added [Translation].¹⁹

The Science Council's sectoral technology strategy study (which examined 15 industrial sectors²⁰) has attempted to go beyond simple macroeconomic output measures of innovation such as R&D expenditure as a percentage of gross domestic product. One of its conclusions is that R&D spending must be evaluated in the context of a firm's technology strategy, which in turn is closely linked to its business strategy. Because Canadian firms tend to compete on the basis of low-cost production of commodities, they also tend to favour adopt and adapt technology strategies and to concentrate on process R&D.

The sectoral study also points to a host of factors that influence the environment for innovation and have a determining impact on the business strategy of a firm. These include tax and non-tax incentives, infrastructure for innovation, labour-management relations, education and training programs (which provide the highly skilled labour pool), a technology diffusion system, marketing support, and technology adoption mechanisms. These mechanisms are important for a country that must rely on the rest of the world for about 98 per cent of its technology and has only just begun to adopt and integrate lean production techniques from abroad.

An interesting example of lean production, combining traditional manufacturing technologies with advances in management science, is the wide field of advanced manufacturing technologies. The world market for AMT is expected to expand to over \$170 billion by the year 2000.

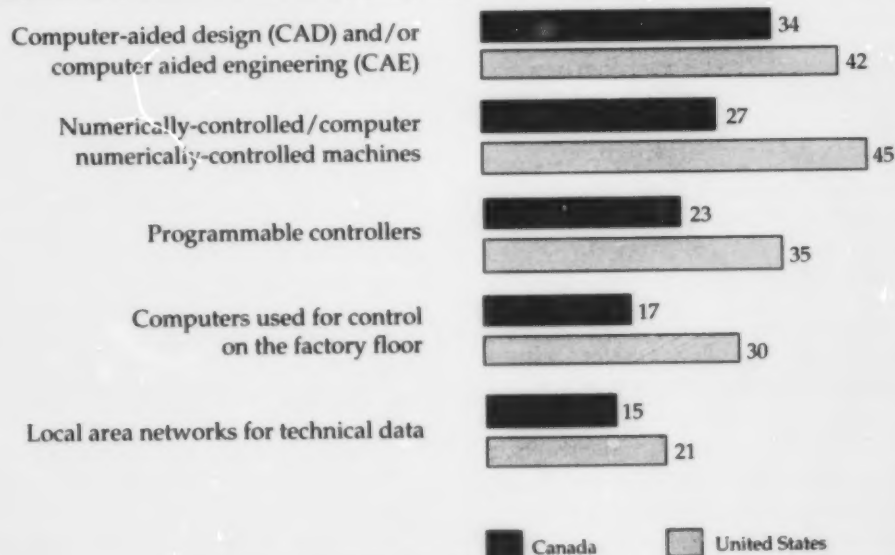
A recent study of the uptake of these new technologies in Canada and the United States indicated that they were being used to some degree in 48 per cent of Canadian manufacturing establishments; the most frequently used technologies were programmable controllers, computer-aided

design and engineering, and numerically-controlled/computer numerically-controlled machines (Figure 1). To date, Canadian firms have made little use of other advanced technologies being adopted by U.S. manufacturers – technologies including artificial intelligence, expert systems, material-working lasers, and automated guided-vehicle systems.²¹

The federal government and some provinces have introduced measures to help correct this AMT weakness in Canada. For example, the \$8.5 million Advanced Manufacturing Technologies Applications Program run by Industry, Science and Technology Canada helps firms hire experts to deal with problems related to the acquisition of new technologies. The program has been well received and the government is exploring the potential for continuing the program.

Quebec has been particularly active in promoting the adoption of new technologies in small and medium-sized firms. In Quebec in 1988, new technologies were being adopted by 35 per cent of plastics firms, 70 per cent of electrical/electronics firms, and 42 per cent of firms in transportation materials. But there are problems, as the Quebec author of the OECD study on the subject notes:

Figure 1. Use of Technology in Canada and the United States, Percentages of all Establishments



Source: Statistics Canada, *Indicators of Science and Technology 1989: Survey of Manufacturing Technology*, cat. no. 88-002, 1 (4) (Ottawa: Minister of Supply and Services, 1991), 39.

The problem is that many top executives of SMEs believe that buying new technologies is not worthwhile.... What they don't realize is that their competitors already own such new equipment [Translation].²²

Several private organizations are promoting AMT. The Canadian Manufacturers' Association, for example, has designed Can-Mate, a technology exchange program that helps Canadian manufacturers access information on AMT. Related to this was the introduction in 1990 of the CMA's "Compete to Win" initiative, established to develop a state-of-the-art management training program that would give Canadian manufacturing firms the skills they need to compete. Such moves will facilitate the introduction of new technologies; however, little progress is likely unless Canada attends also to the development of a literate, numerate workforce.

Various industrial sectors, aided by the federal government, are developing strategies and organizing themselves to face international competition. The following items are examples of recent initiatives:

- VISION 2000, \$30 million worth of cooperative R&D projects in personal communications, launched last year by an alliance of telecommunications companies;
- a five-year initiative on the part of the software industry aimed at tripling Canada's base of software products companies with annual sales of over \$10 million;
- a microelectronics sector campaign centred on the newly created Strategic Microelectronics Consortium, which will manage cooperative technology development projects;
- a memorandum of understanding between the pulp and paper industry and Industry, Science and Technology Canada to provide some \$60 million for R&D in pollution abatement;
- the study phase of a possible sector campaign (with assistance from ISTC's Sector Campaign Program) in the area of medical devices.

Strategic Alliances

Strategic partnerships or alliances are increasingly being created by Canadian firms to meet the challenge of international competition. These alliances are either between domestic firms or

between domestic and foreign firms, and may cover everything from marketing and distribution to R&D agreements. Some examples of recent alliances include:

- Northern Telecom's link to the U.K.'s Storage Technology Corporation in the area of optoelectronic development;
- a \$25 million agreement between IAF BioChem International of Montréal and Glaxo of the United Kingdom to develop an IAF product that will be used to treat AIDS;
- a joint venture between Cascades Inc. of Quebec and Le Groupe Pinault of France in the area of newsprint technology;
- an agreement between Canadian Foremost and AB Haggblunds and Soner of Sweden to jointly manufacture an amphibious vehicle in Canada for the North American market.

An analysis of alliances struck by 35 Canadian firms in the electronics industry indicates that about half were for new product and process development.²³ The geographic distribution of the alliances was as follows: Canada, 47 per cent; European Community, 18 per cent; United States, 6 per cent; Japan or Korea, 6 per cent; mixed/other, 23 per cent. Canada's biotechnology industry also engages extensively in strategic alliances; the new materials sector less so.²⁴

Because small firms find it difficult to enter or even explore such arrangements, governments have introduced a number of measures to help them acquire the market intelligence required to form such alliances.²⁵ Investment Canada, for example, has developed a range of vehicles to assist companies looking for partners, as well as to inform prospective foreign investors about the advantages of alliances. Kits have been developed that provide profiles of Canadian industrial and research capabilities in optoelectronics, wastewater management, biotechnology, ocean technology, electronic technologies, artificial intelligence, and advanced software.

Risky Business

Lacking the resources of established companies, nascent technology-based firms need financial support to reach a size that allows them to compete effectively. It is estimated that early-stage technology-intensive firms need a dollar of working capital for each dollar of sales.

Table 1. Venture Capital Financing of Technology Companies, Selected Countries, 1989

	Average Number of Investors	Average Investment ¹ (\$ thousands)	Average Financing ² (\$ thousands)
1989			
United States	3.08	699	2157
United Kingdom	1.37	919	1263
France	1.58	634	1005
Canada	1.10	599	657
1985			
Canada	1.33	661	886
% Change 1985-1989	(17%)	(9%)	(25%)

¹ Amount invested by one venture investor in a particular round of financing.

² Total amount invested in a particular round of financing.

Source: Mary Macdonald, *Creating Threshold Technology Companies in Canada: The Role for Venture Capital*, discussion paper (Ottawa: Science Council of Canada, 1991), 18.

Venture capital is a major source of financing for such firms. Yet the availability of venture capital for technology-intensive ventures has been deteriorating (Table 1), leaving Canadian companies with small infusions of capital and less venture capital support while foreign competitors are accessing significantly larger amounts from several venture sources.

The fact that knowledge-based companies, such as those in biotechnology, materials, and informatics, have had difficulty with financing is an indication that the Canadian financial community, particularly the banks, has not adjusted to the fact that computers and germ plasms are just as much commodities as are wheat and nickel. The venture capital community, for its part, argues that the shortage of venture funds is due to a lack of confidence in technology entrepreneurs. This situation has an adverse effect on the leading edge of industrial innovation in Canada. As a consequence, several analysts have argued that the focus in Canada should be more on people than on financing. A Science Council discussion paper has proposed a three-R approach – retain our most experienced managers and our corporate clout; recruit experienced entrepreneurial managers and strategic corporate partners; and return Canadian-bred talent that has moved away. Developing such a strategy would “allow the Canadian venture capital industry to achieve

the critical mass it needs to play an effective role in supporting the development of successful Canadian technology companies.”²⁶

Biotechnology companies have found it particularly difficult to attract capital over the past few years. The National Biotechnology Advisory Committee has pointed out this critical concern, noting “a lack of equity financing in Canada to support new businesses and the significant cost of taking new technologies and new products through to market.”²⁷ Major problems exist in the seed and mezzanine financing of newly established biotechnology firms, but, although private capital has been difficult to find (thus contributing to the takeover of some of Canada’s flagship biotechnology concerns, such as Connaught Laboratories Ltd.), innovative private-public financing sources have been created to deal with the shortfall. An example is the creation in 1990 of Bio-capital, a venture fund for start-up firms in areas such as pharmaceuticals, environmental technology, and agricultural developments. The fund, managed by the Fonds de Solidarité (on behalf of Quebec’s labour unions) along with British and Belgian partners, has invested approximately \$3 million in five firms to date.

There are signs that equity for some biotechnology firms is improving. Allelix Biopharmaceuticals has gone public (on the tail of one of the most successful years ever for public share

offerings on Wall Street: biotechnology firms alone raised \$2 billion), and IAF Biochem and Biomira have witnessed significant gains in the value of their equity.²⁸

On balance, however, there are disturbing signs that private sector venture capital groups have been steadily reducing their support for Canadian technology companies. Canadian biotechnology venture funds, for example, are severely undercapitalized compared to U.S. biotechnology venture funds; average investment in early-stage biotechnology companies in 1989 amounted to \$588 000 in Canada and \$2.4 million in the United States (Figure 2).

Besides the public-private financing initiatives mentioned above, another innovative mechanism for raising capital investments in technology-based firms is the tax shelter, a mechanism well developed in Quebec. Not only have a number of instruments been developed to enhance the SME technology base in the province, but innovative

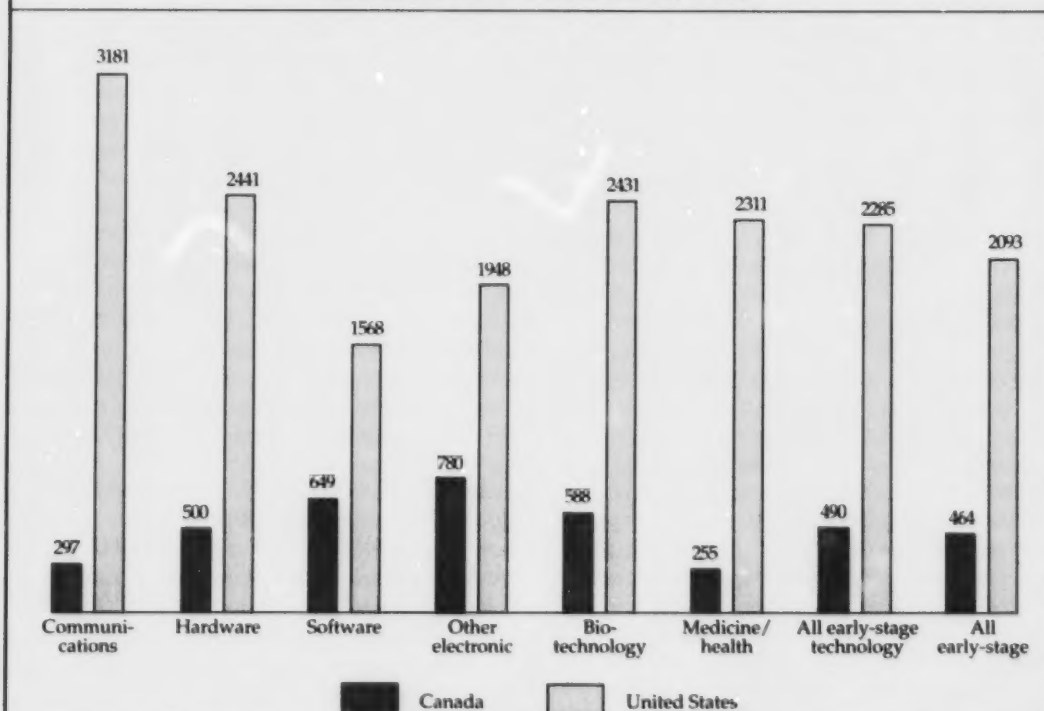
schemes have been promoted to finance promising university research and affiliated hospital research. Several Quebec universities were successful in raising equity in this fashion, notably McGill University's Martlett Investment Inc., which assembled over \$90 million for 25 R&D projects through a two-phased offering. Although Quebec's tax shelter plan has since been modified, it remains a highly innovative method of encouraging synergy between industry and universities and greater participation by citizens in R&D-based initiatives.²⁹

Government Initiatives: Supporting Industrial Innovation

Federal Level

Procurement: Government procurement of major goods and services can serve as a significant stimulus to innovation. Indeed, Canadian governments generally endorse the principle of fostering

Figure 2. Average Funding (\$ thousands) for Early-Stage Technology Companies, Canada and the United States, 1989



Source: Mary Macdonald, *Creating Threshold Technology Companies in Canada: The Role for Venture Capital*, discussion paper (Ottawa: Science Council of Canada, 1991), 21.

the development of world-class Canadian technology-based products through procurement programs such as the Canadian Annual Procurement Strategy (which determines the long-range capital acquisition plans of major government departments) and the Defence Industry Research Program (which strengthens the research and technological capability of the Canadian defence industry).

Governments also use procurement to promote supplier development linkages between large firms and small and medium-sized businesses. The informatics area is an example. Most of the firms selling information technology products and services in Canada are foreign-owned. Government procurement is used to encourage these firms to do more development and manufacturing in Canada and to export more from Canada. Firms can obtain a "rationalized" status vis-à-vis government procurement by meeting requirements to undertake world-product mandates and to assist in the development of an information technology infrastructure in Canada (e.g., supplier development and university research). An example of the impact of this policy is the fact that Hewlett-Packard (Canada) Ltd. of Mississauga has agreed to spend \$120 million on R&D and manufacturing technologies to support some \$600 million of anticipated sales and exports over the next five years.

At the beginning of 1992, the federal government announced it would re-introduce its Unsolicited Proposals Program in a slightly modified form. Despite its immense popularity with the private sector, the UP Program was cancelled in 1989. The modified program, the Science and Technology Procurement Brokerage Service, builds on the same philosophy as its predecessor: it is procurement-driven with a "demonstrated first user" requirement – that is, the Crown acts as a demonstrator for the innovation so that it can be picked up by other potential buyers. In a significant shift from previous policy, the intellectual property right goes to the contractors in most cases. To complement this new program, the federal government also announced a \$20 million Environmental Innovation Program, which stimulates procurement in environmental technologies. The program offers contracts to industry, universities, aboriginal groups, nongovernmental organizations, and individuals provided that the proposals accord with Green Plan objectives.

Spectrum Allocation: Regulations, like procurement, can be used to stimulate innovation. The Department of Communications (DOC) has begun exploring how to use its spectrum licensing authority to increase incremental R&D in the communications sector. Cantel, for example, in its 1985 bid for its cellular licence promised an industrial benefits package that included a commitment to re-invest 2 per cent of its revenues in R&D. As well, Cantel's package included a pledge by its principal equipment supplier, Ericsson Communications, to initiate value-added services in Canada. Since 1985, Ericsson has expanded its R&D staff to about 200. When DOC renewed Cantel's licence in June 1990, the firm extended its commitment to invest 2 per cent of revenue in R&D with the understanding that other firms would be under the same obligation. DOC is currently developing a policy that will establish criteria of R&D commitments as a condition of licence.

Large-Scale Projects: Over the years, Canada has often used large-scale ventures to drive economic development and technological innovation, with mixed results ranging from the Avro Arrow to the Bras d'Or hydrofoil, Manic, and Alouette. A 1991 analysis of 79 post-war projects in energy, defence, communications, and transportation underscores the role of the public sector as a significant supplier of technology (Table 2).

Two other projects offer important technological opportunities for Canada. One is the development of a country-wide high-speed communications network for R&D and education. Promoted by Industry, Science and Technology Canada, this \$60 million, five-year project will involve public and private sector partners in the implementation and operation of a 1.5 megabit/second network. This will be a major upgrade from the current 56 kilobit/second technology. The incremental net present value of the new network is estimated to be \$1.5 billion, including \$810 million from productivity gains and \$695 million from the provision of an environment for technological development and innovation.

The second project is the high-speed train. Following the initial feasibility study released in June 1991, the federal government agreed to team up with Ontario and Quebec to do a detailed evaluation of developing a high-speed train (300 kilometres/hour) to operate in the Québec-Windsor corridor. In a related activity, l'École Polytechnique of Montréal has taken the lead in

Table 2. Characteristics of the 10 Projects with the Highest Investment Levels

Project	Sector	Principal actor	Cost 1988 \$ millions
La Grande	hydro	public/private	15 300
Darlington	nuclear	public	12 500
Manic Outards	hydro	public/private	8 500
CF-18	aircraft	public/private	6 400
Frigates	defence	public/private	6 200
Bruce B	nuclear	public	5 900
Pickering B	nuclear	public	4 400
Peace River	hydro	public	4 000
Syncrude	oil sands	public/private	3 800
Digital World	communications	private	3 500

Source: Philippe Faucher and Kevin Fitzgibbons, *Public Demand and the Management of Technological Risk in Large-Scale Projects* (Montréal: Université du Québec à Montréal, 1991), 12.

exploring the establishment of a North American centre of excellence in high-speed rail, which would link the industrial development infrastructure of Canadian and U.S. research institutions and industry.

Retooling Industrial R&D Support: Over the past year or so, some important changes have been made to the federal portfolio of support programs. For example, technology diffusion programs have been developed to improve the availability of information and technical support for Canadian firms. Innovative initiatives in this area include the Technology Transfer Information Service (operated by the Canadian Industrial Innovation Centre at Waterloo to tap international technology for Canadian needs) and the Manufacturing Visits Program (designed to help Canadian industry improve its international competitiveness through visits to role model firms in different sectors).

There have also been revisions to some long-standing and successful industrial support programs such as the Industrial Research Assistance Program. In 1991 IRAP was the focus of a controversial restructuring by its manager, the National Research Council. Following the release of a new strategic plan for IRAP, a number of users criticized proposals to reduce the number of existing IRAP elements and encourage greater decentralization. The Parliamentary Committee on Industry, Science and Technology, Regional and Northern Development waded into the fray with an inquiry into the proposed changes and

offered some recommendations (similar to those of an industrial advisory group, which had been appointed and then disbanded by the NRC) on the future of IRAP. For example, the federal government should increase its funding of IRAP and re-examine the appropriateness of keeping IRAP within the NRC; the NRC should justify the increased decentralization and alteration of the IRAP elements and re-establish the IRAP Advisory Board.³⁰ In the current context of fiscal restraint and public accountability, it is clear that such industrial support programs will continue to receive more attention as the federal government reconfigures support for industrial innovation to better reflect new priorities.

Provincial Level

At one time or another all provincial governments have developed explicit S&T and industrial strategies and experimented with a range of instruments for promoting technology development. A Nova Scotia economic strategy outlined in November is one such example. As the strategy states:

If Nova Scotia companies are to succeed in the global marketplace, they cannot simply hope that they will somehow gain access to world-leading technologies by osmosis. The province must have its own commercially oriented science and technology infrastructure to develop, adopt, improve and customize the technology we need.³¹

British Columbia, which introduced a science and technology policy in 1987, has a wide range of measures to strengthen and encourage industrial innovation, including:

- SPARK (Strategic Planning for Applied Research and Knowledge), a joint private-public sector process involving examinations of a series of industrial sectors strategic to the provincial economy;
- a five-year \$420 million Science and Technology Fund announced in 1990 as a source of investment for companies and institutions involved in applied research, development, and the commercialization of technology;
- the British Columbia Research Corporation, a \$12 million operation that helps firms develop and apply science and technology for economic growth.

Other initiatives would be too numerous to mention, but it is clear that, compared with the federal government, provincial governments tend to be more targeted and selective in supporting industrial innovation. To highlight some features of the provincial approach to innovation, we describe certain initiatives in Ontario and Quebec, provinces that account for over 65 per cent of total provincial investment in R&D.

Ontario's principal vehicle for stimulating industrial innovation is the Industrial Research Program (IRP) component of the province's \$1 billion 10-year Technology Fund announced in 1987. The announcement of this fund emerged from the work of the Premier's Council on Science and Technology (now the Premier's Council on Economic Renewal), an advisory board designed to assist in the development of long-term strategies for the economic development of Ontario.

In 1989, after an initial round of funding industrial R&D projects, a moratorium was placed on new applications. That moratorium was lifted in 1990, and in May 1991 three new projects were announced:

- a \$14 million project in aircraft control systems. Participants include Menasco Aerospace Ltd, Canadian Marconi Company, the universities of Toronto and Waterloo, and Ortech International;
- an \$11 million project in 3-D imaging involving IMAX Systems Corp., Litton Systems of

Canada Ltd., C&V Engineering, Sonics Associates Inc., the NRC, and the universities of Ottawa, Toronto, and Waterloo;

- a \$7 million project in mobile robots that includes PRECARN Associates, Ontario Hydro, Atomic Energy of Canada Ltd., the universities of Toronto and York, and the NRC.

Apparently, the first IRP-sponsored projects are beginning to bear fruit. As of 31 March 1991 some \$30 million in revenue could be attributed to specific projects.

In 1989, Quebec announced its \$350 million Technology Development Fund. In its May 1991 budget, the Quebec government allocated \$20 million of the TDF to assist small and medium-sized firms. Also announced in 1991 was \$32 million over five years to promote alliances between industry and university researchers.

TDF, like the federal government's \$1.3 billion InnovAction program announced in 1987, the British Columbia Science and Technology Fund, and Ontario's Technology Fund, was designed as a major platform around which S&T and innovation could be mobilized for strategic objectives. It supports projects that aim to adopt, adapt, and develop new technologies or processes through industrial collaboration with academic and parapublic research establishments (see Box 1 for examples).³² The Quebec fund is also being used to finance the province's contribution to Radarsat and the Institute for Magnesium Technology in Québec. In addition, TDF includes a special component for environmental projects.

Another major announcement in Quebec's May budget was a two-year \$200 million Industrial Development Fund geared to advanced-technology sectors such as transportation equipment, plastics processing, aeronautics and aerospace, pharmaceuticals and biotechnology, and electronic products. More recently, there came the announcement in December 1991 of a major industrial development strategy for Quebec that placed a premium on upgrading the knowledge-intensive "industrial clusters" in the province. The release of this strategy prompted Michael Porter (having just completed his examination of Canada's competitiveness) to voice his support for the approach. The impact and progress of this model in changing the traditional mindset will be closely followed.

**Box 1. Selected Projects Supported by the Quebec
Technology Development Fund**

Electronic Printing		Total cost, \$39 million
Industry leader:	XMX Corp.	
Industry partner:	Unikunz Canada	
Research agencies:	École Polytechnique Centre de recherche industrielle du Québec (CRIQ)	
PROGERT (Forest Engineering Geomatics)		Total cost, \$28.8 million
Industry leader:	SNC Group Inc.	
Industry partners:	Bureau des consultants en gestion du territoire (BCGT) Inc. Computertime Network Corp. Hauts-Monts Group Inc. IBM Canada Ltd. Innotech Aviation Ltd. Intera Information Technologies Corp. PCI Inc. Poulin Thériault Inc. Spar Aerospace Ltd.	
Research agencies:	Canada Centre for Remote Sensing Centre d'enseignement et de recherche en foresterie de Ste-Foy Centre de foresterie des Laurentides Centre de géomatique (Université Laval) Centre de géomatique appliquée (Limoilou College) INRS-Eau (water) Université de Sherbrooke (CARTEL)	
Technological partners:	Daishowa Inc. Domtar Inc. Donohue Inc. Kruger Inc. Ministry of Energy and Resources Ministry of Forests Stone-Consolidated Inc.	
Telerobotics Development Systems		Total cost, \$11.8 million
Industry leader:	MPB Technologies Inc.	
Industry partners:	CAE Electronics Ltd. Hydro-Québec PRECARN Associates Inc.	
Research agencies:	Canadian Institute for Advanced Research McGill University	

International Initiatives

Since...the scope for action by individual host countries has become rather limited, the need for coordinated multilateral action by all concerned – host countries, home countries, international institutions and transnational corporations – is all the more important.

– UN World Investment Report 1991³³

On a global scale, corporate activity is enormous in areas such as patents, licensing, strategic alliances, marketing ventures, and distributorships. Its extent is heavily influenced by (1) linkages among countries through trade flows, finance, direct investment, and technology, and (2) interrelationships among major influences on the world economic system (e.g., global debt, exchange rates, and the effects of national policies on other countries).³⁴ Corporate strategists must carefully track this dynamic in order to take advantage of global opportunities.

For instance, large Japanese firms have increased their overseas R&D facilities to meet local needs, upgrade existing production facilities, search for the seeds of new technologies, and utilize highly qualified R&D staff.³⁵ Northern Telecom's 1991 announcement of a 20-researcher R&D facility in Japan is an example of a Canadian-based firm undertaking global corporate activity for similar strategic reasons. The Business Council on National Issues placed the matter in perspective: "The importance of Japan now means that, in effect, a firm with no Japan strategy cannot realistically aspire to a world strategy."³⁶

But companies are not the only entities going global. In many instances, they are receiving support from governments who themselves are upgrading intelligence services around the globe. The competitive success of companies is in part due to the effectiveness of these services and the ability of home governments to develop strong foreign relations and trade policies that recognize the critical importance of technology.

It should also be noted that governments often play a key role in supporting international business deals such as Canada's November trade mission to Korea to promote CANDU sales, or the space industry delegation to Japan to promote business opportunities with Asian partners.

The focus of international scientific, technological, and industrial cooperation has traditionally been at the federal level. However, in recent years the provinces have begun to strike their own

international agreements. The provinces spend more than \$100 million annually to maintain 57 independent trade offices in 25 countries.

Much of the activity in these offices concerns technology-based agreements, as the following examples indicate:

- Quebec has signed Memoranda of Understanding with France and with both Flanders and Wallonia (regions of Belgium) to promote bilateral technological and industrial cooperation;
- Ontario has signed MOUs with the so-called "Four Motors of Europe" – the regions of Rhône-Alpes in France, Lombardy in Italy, Baden-Württemberg in Germany, and Catalonia in Spain (and is negotiating an additional agreement with Wales) – to promote close ties in a number of areas including technology transfer and industrial cooperation. In one project, "Telepresence," Ontario has taken the lead in developing an interactive computer-video work station for collaborative work over long distances (i.e., among the four regions and Ontario);
- the Alberta Technology Research and Telecommunications Department has signed agreements with Flanders and Wallonia on bilateral S&T cooperation;
- British Columbia is negotiating an agreement with the state of Saxony in Germany;
- Newfoundland and Labrador signed an MOU in 1989 with Norway's Ministry of Petroleum and Energy to promote technology transfer, industrial cooperation, and training.

The provincial research organizations in several provinces have followed the lead of their provincial governments and developed their own international networks. In the last 12 months or so, the following arrangements were signed:

- the Centre de recherche industrielle du Québec has signed agreements with counterparts in Austria and Italy;
- Ortech International of Ontario has established ties with the Fraunhofer Institutes in Germany, the Production Engineering Research Association and the Electrical Research Association in the United Kingdom, Bertin in France, and Eniricerche in Italy;

- the Alberta Research Council has signed agreements with Eniricerche, the Institute of Technology in Denmark, and the Flanders Centre for Technological Innovation.

A web of provincial-level international relationships is emerging that will obviously pose some questions for the federal level of activity. Quebec's 1991 white paper on international relations devotes an entire chapter to the role of S&T.²⁷ This policy aims to increase technological cooperation with industrialized countries in strategic sectors; augment the international dimension of Quebec's domestic S&T programs; and ensure harmonization with the federal government's initiatives in international S&T projects. Other provincial governments interested in positioning themselves better in the international technology market would do well to examine the Quebec model more closely.

Municipal Level

There is increased awareness at the municipal level that local communities could have an important role to play in the industrial innovation process. Some of this new awareness stems from Science Council activity (jointly with the Canadian Advanced Technology Association and the Canadian Chamber of Commerce) at the community level in the last two years.²⁸

While some communities have organizations to stimulate technology-intensive development (e.g., the Ottawa-Carleton Research Institute), major local initiatives have only begun to emerge. The region of Hamilton-Wentworth has announced the creation of the Greater Hamilton Technology Enterprise Centre, which will provide a "one window" approach to the creation of new ventures in technology-intensive areas such as advanced industrial materials, robotics-based manufacturing of auto parts, and medical devices. The Windsor-Essex region last year established its Prosperity 2000 program and was working towards a technology council on the Ottawa-Carleton model.

Municipalities are also emerging on the international scene. The traditional international "twinning" of municipalities, which was done for political and cultural reasons, are increasingly being supplemented by arrangements that encourage industrial cooperation. For example, the arrangement between Ottawa and The Hague

resulted in advanced technology joint ventures. Windsor and Saint-Étienne, France, will take turns hosting an annual trade show to encourage industrial cooperation in plastic moulding.

Conclusion

The policy issues surrounding industrial innovation in Canada have been discussed for at least the last 25 years. However, it is only recently that these issues have been cast within the broader economic context of international competitiveness. And 1991 can be said to be the year that international competitiveness entered the Canadian lexicon.

A 1991 Angus Reid poll shows that many Canadian business people tend to view global challenges from a limited perspective. Companies see government regulation, lack of venture capital, and their subcritical size relative to international competitors as their greatest weaknesses. With regard to technology, however, many firms see the future a little more optimistically. The private sector has increased its R&D expenditures, particularly in technology-intensive sectors, and has initiated a number of interfirm cooperative activities (e.g., sectoral strategies and domestic and international alliances). However, the Conference Board's *R&D Outlook 1992* indicates that, despite some increase in R&D alliances, "more outgoing and risk-taking attitudes are required from Canadian firms to forge more strategic technology partnerships in the future."²⁹ Corporate strategies must be geared to improving the competitiveness of firms in the face of globalization. Needed is a marketing focus aimed at developing the products to access international markets at a time when technology-intensive trade is becoming an ever larger fraction of total international trade.

Governments for their part have put in place supporting policies and programs. The federal government has found ways to stimulate industrial innovation while having to live within budgetary constraints. For example, it developed an innovative procurement policy for information technologies that seeks an increased commitment from firms to do more R&D and manufacturing in Canada.

At the provincial level, the two provinces in the industrial heartland, Ontario and Quebec, are stimulating industrial innovation through technology development programs and other levers

such as procurement. Other provincial governments (e.g., Nova Scotia, Alberta, and British Columbia) are developing stronger partnerships with the private sector, and are attempting to diversify their economic base. Moreover, the provinces are becoming more involved in establishing international agreements in technological and industrial cooperation. This type of activity should be expected to increase as the federal government transfers more responsibilities to the provinces. The federal government's constitutional proposals will clearly affect the economic union, and to the extent that they reflect the coherence of policies in support of industrial innovation, Canada will face some major challenges.

The municipalities are also increasing their interest in technology and industrial innovation to create jobs and improve their tax bases. New arrangements to facilitate the establishment of new infrastructure are being put in place. Municipalities are also developing international market and technology intelligence networks that tie their regions to others in Europe and elsewhere.

Globalization is forcing a critical debate on the issue of international competitiveness. This in turn is leading the private sector and all levels of government to investigate seriously how they can contribute to maintaining economic prosperity through industrial innovation.

The transformation of the international economy has profound implications for Canada. Our international trade has been based on the large trade surpluses provided by the export of raw materials. However, with the price of commodities decreasing and with new players (i.e., developing countries) exporting commodities, Canada has little choice but to move towards a value-added economy if Canadians are to retain a high standard of living. Trade surpluses will have to be generated in more sectors.

However, Canadians should realize that they are not starting from scratch in developing knowledge-based or "grey matter" industries. There are major strengths in telecommunications, aerospace, and software as well as specific strengths in several niches (e.g., cable television and electric power). Moreover, there is a well-developed publicly funded R&D infrastructure on which to build; one that is gradually being retooled to deal with the new approaches required to confront global competition.

Living next to the United States, Canadians often feel that they are in a technological catch-up situation and, as a result, tend to downplay their

strengths. However, Canadian technology strengths are well recognized in Europe (itself in a technological catch-up situation vis-à-vis North America and Japan). For example, Northern Telecom is currently deploying its digital switching technology in Austria, a country with longstanding ties with Eastern Europe. Vidéotron of Montréal is seizing the opportunity to "cable-up" Europe.

The environment for industrial innovation will greatly be affected by moves towards a North American free trade arrangement. Just as some Canadian companies have positioned themselves to deal with the new Europe of 1993, others have prepared themselves for the new North America. What Canada does to influence its competitiveness will have ramifications south of the border and vice versa. Already, there are indications that federal initiatives are being developed to explore prospects for Canada-U.S. cooperation on issues of common concern, particularly in the area of technology policy and competitiveness. One can anticipate that the next steps will be to prepare joint strategic plans for individual technology-based sectors, not merely on a bilateral basis, but from a regional perspective as well.

Canadians have shown that they can compete internationally when they build on strengths. What are needed are the enabling public and private structures to multiply Canadian successes as rapidly as possible.

Canada's shift to a knowledge-based economy would ensure the high standard of living to which we have become accustomed. Moreover, if successful, such a shift would also promote an industrial innovation system that is more in keeping with sustainable development over the long term.

Notes

1. Canadian Research Management Association, *Forging R&D Linkages between Industry, Universities and Government: A Discussion Paper* (Toronto, 1991), 10.
2. William Taylor, "The Business of Innovation: An Interview with Paul Cook," *Harvard Business Review* (March-April 1990): 106.
3. Cedric E. Ritchie, chairman and chief executive officer, Bank of Nova Scotia, "Canada in a Competitive World: Challenges and Solutions," address to the 159th Annual and Special Meeting of Shareholders of the Bank, Halifax, 15 January 1991.

4. See Mary Macdonald, *Creating Threshold Technology Companies in Canada: The Role for Venture Capital*, discussion paper (Ottawa: Science Council of Canada, 1991).
5. In January 1992, the Canadian government offered support for GATT provisions that would give more international patent protection to prescription drug manufacturers. While this has won praise from the brand-name pharmaceutical companies, it has led to complaints from both the generic drug companies and consumers who believe that these measures will only serve to boost the price of drugs for Canadian consumers. The debate is far from over.
6. Robert Reich, interview by Pamela Wallin on "Question Period," CTV Television Network Ltd., 8 July 1991.
7. *The Canadian Nonferrous Metals Sector*, Science Council of Canada Sectoral Technology Strategy Series, No. 8 (Ottawa: Science Council of Canada, in press).
8. Michael E. Porter and the Monitor Company, *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Business Council on National Issues and Minister of Supply and Services, 1991).
9. A.M. Rugman and J.R. D'Cruz, *Fast Forward: Improving Canada's International Competitiveness* (Toronto: Kodak Canada Inc., 1991).
10. "A Survey of Canada: For Want of Glue," *The Economist* (29 June 1991).
11. National Advisory Board on Science and Technology, Committee on the Financing of Industrial Innovation, *Final Report* (Ottawa, 31 March 1991) and *Learning to Win: Education, Training and National Prosperity*, report of the Human Resource Development Committee to the Prime Minister of Canada (Ottawa, 1991).
12. Prosperity Secretariat, *Learning Well...Living Well* (Ottawa: Minister of Supply and Services, 1991).
13. "Innovation: The Machinery of Growth," *The Economist* (11 January 1992): 17-19.
14. This is the official count; however, there are arguments that the scale of industrial R&D may be higher due to undercounting of small and medium-sized firms and modifications to the definition of internationally recognized R&D activity.
15. Statistics Canada, *Industrial Research and Development Statistics 1989 (with 1990 and 1991 estimates)*, cat. no. 88-202 (Ottawa, 1991), 21.
16. "Technology and Telecommunications," special report, *Financial Times of Canada*, 16-22 September 1991, A4.
17. Figures courtesy of Industry, Science and Technology Canada, S&T Economic Policy Division.
18. Canada, Patented Medicine Prices Review Board, *Third Annual Report for the Year Ended December 31, 1990* (Ottawa: Minister of Supply and Services, 1991), 18-22.
19. (Original quote: Notre réussite collective passe maintenant par la transition rapide d'une économie de production de masse à une économie de valeur ajoutée.) Government of Quebec, *Le Québec compte déjà cinq grappes industrielles concurrentielles et huit grappes stratégiques*, communiqué, Montréal, 2 December 1991.
20. The 15 sectoral reports will be published by the Science Council in the spring and summer of 1992.
21. Statistics Canada, *Indicators of Science and Technology 1989 - Survey of Manufacturing Technology 1989*, cat. no. 88-202 (Ottawa: Minister of Supply and Services, 1991).
22. (Original quote: Le problème est que beaucoup de dirigeants de PME croient que l'achat de nouvelles technologies ne vaut pas la chandelle.... Mais ils oublient que leurs concurrents sont déjà équipés avec de nouvelles machines.) This quote is from an interview with Pierre-André Julien, directeur, Groupe de recherche en économie et gestion des PME, in "Le Québec et les robots," *La Presse*, 3 October 1991. See also Pierre-André Julien et al., *La diffusion des nouvelles technologies dans trois secteurs industriels* (Québec: Conseil de la science et de la technologie, 1988).
23. J. Niosi and M. Bergeron, *Technical Alliances in the Canadian Electronics Industry* (Montréal: Centre de recherche en développement industriel et technologique, Université du Québec à Montréal, 1991).
24. *Canadian Biotech '89: On the Threshold* (Ottawa: Winter House Scientific Publications, 1990); and J. Niosi, *Strategic Technological Partnerships in Canadian Advanced Materials* (Montréal: Centre de recherche en développement industriel et technologique, Université du Québec à Montréal, 1992).
25. Ontario Ministry of Industry, Trade and Technology and Industry, Science and Technology Canada, *How to Form and Manage Successful Strategic Alliances*, booklet (March 1990).
26. Mary Macdonald, op. cit. (note 4), 59.
27. Canada, National Biotechnology Advisory Committee, *National Biotechnology Business Strategy: Capturing Competitive Advantage for Canada* (Ottawa: Industry, Science and Technology Canada, 1991), 1.
28. *Research Money* (13 November 1991).
29. This initiative and others were discussed at a major conference on R&D financing in Montréal in November 1991. For a brief summary of the highlights, see *RDI Québec* 1(1) (December 1991): 2-3.
30. For further details on the IRAP situation, see the feature report in *Research Money* 5(17) (30 October 1991); and Canada, Standing Committee on Industry, Science and Technology, Regional and Northern Development, *IRAP: An Inquiry into the Industrial Research Assistance Program* (Ottawa: December 1991).
31. Voluntary Planning, *Creating Our Own Future: A Nova Scotia Economic Strategy* (Halifax, November 1991).
32. For a description, see Conseil de la science et de la technologie, *Science et Technologie Conjoncture*, 1991 (Québec, 1991), 30-31.
33. United Nations Centre on Transnational Corporations, *World Investment Report 1991: The Triad in Foreign Direct Investment* (New York, 1991), 93.
34. Sylvia Ostry, "The Impact of Internationalization," speech to the Institute of Public Administration of Canada, Québec, 27 August 1990.

35. Japan, Science and Technology Agency, *White Paper on Science and Technology 1991* (Tokyo, September 1991), 21.
36. Business Council on National Issues, *Beckoning Opportunities: Towards a Stronger Canada-Japan Economic Relationship* (Ottawa, May 1991).
37. *Le Québec et l'interdépendance: Le monde pour horizon - Éléments d'une politique d'affaires internationales* (Québec, Ministère des Affaires internationales, 1991).
38. See, for example, Science Council of Canada and Canadian Advanced Technology Association, *Firing Up the Technology Engine: Strategies for Community Economic Development*, a joint statement (Ottawa, July 1990); and *Local Initiatives to Promote Technological Innovation in Canada: Eight Case Studies*, Charles H. Davis (ed.), manuscript report prepared for the Science Council of Canada, January 1991.
39. The Conference Board of Canada, *R&D Outlook 1992* (Ottawa, 1991), 8. The 1991 small business report from the federal government devoted a section to encouraging SMEs to weigh the benefits of alliances. See *Small Business in Canada 1991: From Best Practice to Competitiveness* (Ottawa: Industry, Science and Technology Canada, 1991).

3. Infrastructures for Science and Technology

Simply stated, the infrastructures of Canadian science and technology are the sum of scientific, medical, engineering, and technical knowledge in human, institutional, and "hardware" forms.

The following pages form a selective guide to some of the more important events of the past year in the national debate on the conditions necessary to create sound underpinnings for Canadian science and technology. The discussion is by no means comprehensive; any such conspectus would have to take account of the effects of more traditional infrastructures such as those in transportation, energy, communications, agriculture, and health care.

It is important to note that science and technology are related but separate realms of endeavour, with different origins, value systems, and knowledge structures. As John Polanyi (one of two resident Canadian Nobel Prize winners in science) reminds us: "As long as we continue to overlook the existence of science, confusing it with technology, we shall continue to be in trouble with both."¹

It will help to retain this distinction by describing science infrastructure as typically consisting of public and parapublic research facilities, highly skilled people, effective networking among the key stakeholders, and a strong funding base that is premised on long-term continuity.

An industrial innovation and technology infrastructure, on the other hand, comprises organizations and associated institutional systems in the business of either adopting or adapting available technology, or engaged in creating and maintaining core competencies as described in the foregoing section, "Competing through Innovation."

Issues linking these two infrastructures involve the degree to which the educational system is well maintained, and the extent to which issues of technology transfer and government framework policies can be adequately handled (e.g., intellectual property guidelines, procurement, the regulatory framework, precompetitive research, tax and non-tax incentives, labour-management relations, technology diffusion, marketing support, and international outreach services).

The elements of effective and efficient infrastructures for science and technology are complex and strongly interconnected with other factors (including a well-developed S&T workforce)

outlined elsewhere in this report. While in these pages we cannot hope to deal with all of these elements, the following checklist of factors underpinning the creation of scientific knowledge and the development and application of technology will serve as a context for our discussion:

Technology Infrastructure

- the role of the private sector and its gatekeepers (industrial and trade associations) in championing entrepreneurship and innovation;
- the ability of corporations to develop competitive competencies by managing a strategic architecture that places a premium on effective "bundling" of skills (including training);
- an understanding of the mechanisms for management and marketing of technology and its overall valuation within the corporate culture;
- the capability of businesses to engage in adopt and adapt technology strategies.

Technology Transfer/Diffusion Infrastructure

- adequate financing, incentives, and rewards for research, entrepreneurship, and innovation;
- the scale, scope, and effectiveness of linkages between key institutions within the R&D system;
- the mechanisms for sifting through priorities for S&T;
- the measures used to identify and assess indicators of the orientation, direction, and progress of S&T;
- the effectiveness of the governmental decision-making system on S&T-related issues;
- the overall coherence with other national policies (e.g., those affecting education, training, investment, entrepreneurship, trade, aid, foreign relations, immigration, and culture);
- the information/regulatory/legal framework that underpins the creation, use, and impact of science and technology;
- the synergy of producers, suppliers, customers, and competitors in a given area (large or small).

Science Infrastructure

- the value put on basic research and the scientific enterprise by society, including institutions designed to assess and facilitate the appreciation and impact of science on society;
- the appropriate role of governments and higher education in stimulating scientific research and ensuring the existence of necessary bridges to the productive sectors;
- the interdependence and linkage of the national S&T system with international activities abroad;
- the production of skilled personnel;
- the conduct of frontier research;
- the creation and maintenance of unique facilities and instrumentation.

Context Is Everything

The debate on Canadian science and technology policies would be greatly improved if our elected representatives and the custodians of S&T would take the following precept to heart:

...economists and other social scientists will benefit enormously in both accuracy and impact of their analyses, if they drop their conceptualisations of science and technology as activities producing easily transmissible and applicable "information", and recognise them instead as search processes and skills embodied in individuals and institutions.

— Keith Pavitt²

Science and technology grow not in a vacuum but within a complex of interrelated support institutions and decision-making apparatuses. This complex, if well integrated with the broad canvas of other public policy instruments such as education and monetary, fiscal, and regulatory mechanisms, and if well stocked with creative individuals, provides the necessary conditions for both technological innovation and growth in science.

Science is dependent on the public purse, and consequently must deal with public expectations. As *The Economist* has pointed out:

Governments spend huge amounts of money not because they think it adorns their culture as opera does (though this comparison is quite commonly made by scientists) but because

ever since a nuclear-fission bomb exploded in the New Mexico desert in 1945 they have been tremendously impressed with the ability of today's scientists to produce new technologies and with the ability of new technologies to produce new industries.³

Rightly or wrongly, it is this perception of the importance of science to the economy that prevails in much of the Western world. The scientific community, however, is still struggling to come to grips with this perception.

Because of this prevailing public notion of the role of science (and the public's association of science with technology), it follows that proper maintenance or upkeep of its science and technology infrastructure is essential if a nation is to position itself at the forefront of international developments. Furthermore, it is the responsibility of governments, in close cooperation with industry, academe, and labour, to ensure that the necessary upkeep takes place.

Science Policy for What? What Science Policy?

Does Canada have a science policy? I am sure some of my fellow cynics out there are wondering whether I am going to have sufficient intestinal fortitude to give a one-word, two-letter speech, and then sit down. And I have to admit that I am tempted.

— Gordon MacNabb⁴

Of course, in a federation such as Canada's, the different levels of government have perceived a need to intervene in science and technology policy issues for different reasons, and with differing results. The approach taken by the federal government and by other levels of government in support of science and technology and innovation has had considerable impact on the S&T infrastructures.

An example of the attention given to S&T is the 1991 discussion on Maritime economic integration by the Council of Maritime Premiers, which underlines the need for enhanced coordination among research bodies serving the region. In particular, the three science and technology advisory bodies in New Brunswick, Nova Scotia, and Prince Edward Island have reviewed ways to improve technological innovation and diffusion in the Maritimes; to improve the general attitude toward science, engineering, and technology

among businesses, governments, and educational institutions; and to increase the number of students pursuing careers in science and engineering.⁵

In this example, and others that bridge the link between science and economic activity, a central question emerges: Science policy for what?⁶ In fact, the debate in Canada has not changed substantively (though the context has) since the formative years of the nation. The essential questions remain: What is the objective of Canadian science and technology policy as seen by citizens and translated by politicians? Is it national prosperity? If so, for whom? Is it to overcome regional disparity, to bootstrap the communities throughout the country with more judicious use of the fruits of science and technology? Is it to offer a higher quality of life for Canadians? Is it for international prestige? Is it for industrial competitiveness and increased market access?

The lack of answers has been a perennial frustration of public policy and the bane of our academic, industry, and labour leaders. Of late, the concern has shifted to the "competitiveness" of Canadian industry (discussed elsewhere in this report), as this issue is front and centre on the government and business agenda. It is, however, not at all clear that sufficient attention is being paid to other national objectives requiring the input of science and technology. Nor is it evident that adequate consideration is being given to the maintenance of a research infrastructure that will be conducive to the new competitiveness paradigm – one that recognizes the role of scientific knowledge, industrial innovation, and, above all, creative individuals.

The Challenge: Moving Science and Technology to the Centre

Science and technology were once the conditions of our civilization.... More recently they have been regarded as vitamins, tiny quantities of which could prevent stunted growth and enable us to absorb our industrial nourishment. Now they must be reckoned as the very meat and potatoes of our economy.

– Derek J. deSolla Price⁷

For the past several decades, the two major funders of R&D, governments and business, have stressed that science and technology have moved from the periphery to the centre of their respective decision-making systems.⁸ Science and technology, the claim goes, have become major

public policy vehicles for promoting national objectives.

That a well-trained and scientifically literate population is the hallmark of national excellence is today's mantra. That investment in basic research provides sufficient economic returns to justify government subsidization and industrial investment is now almost an article of faith in Europe, Japan, and the United States.⁹ That pace-setting facilities for basic and applied research and training are important components of a nation's infrastructure for downstream technological and production activities is also now accepted.¹⁰

An examination of funding for research and development in Canada reveals the extent to which policy has been converted to action. Table 1 illustrates Canada's gross expenditures in R&D over the period 1984-91. As one can see, the numbers are not comforting, nor is the recent trend. However, a longer-term perspective shows a more realistic picture.

Federal government funding for R&D has increased from \$600 million in 1972 to \$2.78 billion in 1991. Business has increased its share of R&D funding from \$370 million to \$4.05 billion in the same period.¹¹ Over these same years, another marked shift has occurred that has seen the government share of gross expenditures on R&D drop from 45 per cent in 1972 to 29 per cent in 1991, with the business share going in the opposite direction from 27 per cent in 1972 to an estimated 42 per cent in 1991.¹²

This trend is not unique to Canada; the decrease in the government share is a long-term tendency shared by all OECD countries. It results not only from government downsizing forced by fiscal restraint, but equally from the growing importance accorded to other public programs, including health, education, and environmental programs, and the current predominance of market-based policies in most Western economies.

The significant growth in business investment in R&D is partly owing to the federal government's introduction of investment tax credit incentives in 1977. Investment in industrial R&D grew from just over \$1 billion in 1977 to \$3.3 billion in 1990 (1981 dollars). Today, Canada's absolute dollar investment in business R&D is the seventh largest in the world.

In its annual review of industrial R&D spending intentions, the Conference Board of Canada provides a useful barometer of how the business sector views investment in R&D. It is interesting to note that even during the recent recessionary

Table 1. Canada's Gross Expenditures on Research and Development, 1984-91

	1984	1985	1986	1987	1988	1989	1990	1991
	(\$ millions)							
Actual	6 112	6 810	7 325	7 678	8 232	8 718	9 206p	9 714
1986 \$	6 420	6 977	7 325	7 326	7 504	7 587	7 782	7 866*
	(percentage)							
Annual real growth	8.9	8.7	5.0	0.0	2.4	1.1	2.6	1.5*
GERD/GDP	1.37	1.42	1.44	1.39	1.36	1.35	1.37	1.40*

p preliminary data.

* ISTC estimate.

Source: Industry, Science and Technology Canada, S&T Economic Analysis Division, *Selected Science and Technology Statistics 1991* (Ottawa, 1992).

period, Canadian industry expressed an intention to increase its R&D spending for 1991 at a rate higher than inflation. The forecast is not as rosy for 1992, but is expected to pick up after that.¹³

The private sector has also had much to say over the past decade about controlling the agenda for innovation. As the Chamber of Commerce baldly put it,

It is imperative that Canadian industry assert control of the science and technology agenda and ensure that the very large multi-year expenditures which are made in this area stimulate private sector initiative.¹⁴

Northern Telecom's Vice-Chairman, David Vice, has sounded the alarm more forcefully:

Our challenge is to fire up the technology engine in Canada. This means we must invest our limited resources on R&D *with a purpose*, meaning research and innovation that makes our plants, our products and our workers more competitive globally.¹⁵

And yet a great deal of our national debate still focuses on the fact that it is the industrial sector – for a number of reasons, mostly structural – that has not carried its weight regarding investment in innovation.¹⁶ The hot-potato game being played in Canada with one sector passing the responsibility to the other and vice versa has not been a particularly productive exercise. As a former president of Digital Equipment Corporation put it,

Canada will have R&D in the private sector when we have a private sector that needs R&D. We will have a private sector that needs R&D when we begin to treat technology as a strategic instrument of industrial development in the same way that countries like Japan, Germany and Sweden have done. This will happen when we have leaders in both the public and private sectors who want to make it happen.¹⁷

Because we have benefited from a high standard of living, we like to measure our performance against that of other industrialized nations, particularly those that belong to the rich, industrialized club known as the G-7 (Group of Seven). As a member along with the United States, Japan, France, Germany, the United Kingdom, and Italy, Canada has enjoyed the fruits of middle-power status.¹⁸ But once Canadians are caught up in this comparison (and none of these nations have an industrial structure or economy remotely similar to Canada's) we find ourselves valiantly trying to keep up a respectable image. Some of this effort is engendered by how others view us. As the prestigious British science journal *Nature* saw us in 1988,

Canada spends substantially less of its gross domestic product on research and development than any other large industrialized nation in the world. No matter how it is modified or recalculated to cast it in a better light, that fact still represents the departure point for understanding how Canadian science has arrived at its present state, and where it may go in the future.¹⁹

According to various international bodies that annually project the economic health of the industrialized nations, Canada is a world leader. For example, the 1991 overall ranking of international competitiveness by the World Economic Forum (a complicated assessment that should be read with circumspection) dropped Canada a notch to fifth place from the 1990 ranking of fourth place.

These assessments focus largely on macroeconomic indicators such as the stability of the economy, inflation rates, productivity growth, and foreign exchange rates. Although they are critical to a sound infrastructure, they are by no means the whole of the equation.

As the World Bank's *World Development Report 1991* suggests, achieving an infrastructure that allows free rein to the creation and circulation of knowledge is much more complex than mere attention to macroeconomic indicators. It also includes such factors as a competitive microeconomy, investment in people, and global linkages.²⁰

Or as Professor Robert Reich of Harvard's John F. Kennedy School of Government has put it:

Technology is not like a scarce commodity to be hoarded. Its ultimate value rests in people's heads. Its development depends on a research infrastructure of excellent laboratories, experienced researchers and teachers, a critical mass of customized research materials and equipment, and networks of well-qualified students.²¹

The Reality of Rhetoric

We need more research, but not only that; we need good research and we need innovation. We must develop a coherent overall science policy so that we can not only meet our economic objectives more effectively but also more realistically face our mounting social problems.

— Senate Special Committee on Science Policy, 1970²²

For the past 20 years, the same issues have guided our science and technology policy debate. In its consultation paper *Prosperity through Competitiveness* released in October 1991, the federal government picks up many of the themes suggested by an earlier report of the National Advisory Board on Science and Technology.²³

Both reports stress the consensus of business and labour leaders that improvements to Canadian competitiveness are linked to better education and training and to increased innovation.²⁴ Both reports challenge government, business,

labour, and all Canadians to improve the country's ability to apply science and technology to increase the wellbeing of all citizens.

To argue that these reports (as well as the Michael Porter study on Canada's competitiveness) offer much that is new would be fallacious. Canadians have heard this song before. But the context has changed.

The tone of urgency in these new reports is clear. Already, a number of the cross-Canada "community talks" being conducted under the federal Prosperity Initiative have pointed to the critical role of science and technology in Canada's economic revival. The challenge will be to follow the words with action.

However, it is difficult to effect change without spending money. Compared with other G-7 nations, where significant increases in national science budgets are becoming the norm, little has changed in Canada's overall expenditure envelope for research. A brief assessment of the federal budget of February 1991 confirms this. The nation's gross expenditure on R&D (GERD) as a percentage of gross domestic product has not grown since its high of 1.44 per cent in 1986 (it is estimated at 1.40 per cent for 1991).²⁵ With these levels and growth rates of GERD to GDP ratio, Canada finds itself in a league with Australia, Ireland, Belgium, and Portugal (see Table 2).²⁶

In the 1991 federal budget, the government indicated that S&T would not be exempt from the 3 per cent cap on public expenditures from 1992 through to the end of 1995. This 3 per cent was expected to provide some \$1.5 billion above existing funding levels (a similar amount to that administered by the federal government's science and technology strategy, *InnovAction*, when it was announced in 1987) for new and enhanced initiatives in support of S&T over the next four years.²⁷ Much of this new money was to be devoted to shoring up the base budgets of the federal research granting councils (a recommendation made by several advisory organizations over the past few years to deal with the decline of funding for university research).

The 1991 budget unfortunately views innovation from a limited perspective — seeing it from a traditional economic viewpoint as a narrow question of incrementally increasing the R&D expenditure envelope.²⁸

Richard Lipsey, an internationally respected economist at Simon Fraser University, has put this issue in a slightly larger context as part of his current five-year project on how science and

Table 2. Expenditures on R&D, Selected International Comparisons, 1989

	GERD/GDP (%)	BERD/GDP (%)	HERD/GDP (%)	GERD (U.S.\$ billions)	GERD per capita (U.S.\$)
Japan	3.04	2.12	0.55	58.0	4.71
F.R.G.	2.88	2.10	0.41	26.7	4.31
Switzerland	2.86	2.14	0.57	3.4	5.06
U.S.	2.82	1.98	0.43	144.8	5.82
Sweden	2.76	1.83	0.82	3.6	4.29
France	2.32	1.40	0.34	19.0	3.38
Netherlands	2.26	1.32	0.47	4.3	2.89
U.K.	2.20	1.37	0.33	17.0	2.98
Canada	1.33	0.74	0.31	6.7	2.56
Italy	1.29	0.74	0.25	10.3	1.80

GERD = gross expenditure on research and development.

BERD = business expenditure on research and development.

HERD = higher education research and development.

Some data are from 1988.

F.R.G. data predate unification.

Source: Industry, Science and Technology Canada, S&T Economic Analysis Division, *Selected Science and Technology Statistics 1991* (Ottawa, 1992).

technology and institutional change in a global economy affect economic growth. He argues:

Science policy does not pertain merely to the advancement of scientific research and activity. The long-term goal of science and technology policy involves the optimal use of science to influence both the rate and direction of economic development.²⁹

Nonetheless, for the Department of Finance to recognize publicly for the first time that Canada's R&D expenditures may be contributing to our productivity is a significant step forward, made all the more pertinent since the then Minister of Finance, Michael Wilson, has accepted responsibility for designing the future of innovation and prosperity as Minister for Industry, Science and Technology and International Trade.³⁰ While it is too early to comment on the newly restructured "flagship" department for economic development and international trade, one might expect that innovation and research have yet another chance.

For their part, a number of provincial governments (e.g., Alberta, Quebec, Nova Scotia, and Ontario) have developed strategies to tackle the challenge of prosperity. Quebec's Minister for Industry, Commerce and Technology, Gérald Tremblay, highlighted the issue in a key speech:

Value added depends to a great extent on our access to relevant information and our ability to manage this information using the latest technology. That's the way of the future [Translation].³¹

Concocting Coherence

As already indicated, science and technology infrastructures are more than just a question of financing mechanisms. They also involve the development of networks of communication, institution-building, and the creation of a coherent system of gatekeepers whose function it is to translate policy concerns into issues that can be

understood and acted upon by elected officials. The gatekeepers range from chief science advisers to industrial trade and research associations to scientific societies and learned academies. They all have roles to play in stimulating and directing the debate on critical concerns affecting S&T.

For example, in 1991, when the federal government threatened to terminate the vital S&T statistics collection capability at Statistics Canada, many of these groups swung into action using various strategies to have the government reconsider (which it did, in part, though there is still some threat to this function as Statistics Canada grapples with more budget cuts).

When the U.S. Congress threatened to kill the Space Station Freedom because of political pressures to place the funds elsewhere, representatives from the Canadian Space Agency, some aerospace industries, and others lobbied hard through the Canadian Embassy and the science and technology counsellor in Washington to make the case for continued funding. (Canada is contributing \$1.75 billion of taxpayers' money to the program.) After considerable debate and pressure from other sources, the U.S. Senate finally voted in favour of continued appropriations, at least for another year.³²

Although much of this work appears ad hoc in nature, Canada does have a formal, institutionalized S&T advisory system, the major elements of which are pictured in Figure 1. If it looks a little complex, it is, but no more so than similar mechanisms and networks in other countries.

However, Canada's situation is complicated somewhat by its federal structure, in which the different levels of government create agencies to deal with research issues and with their functional equivalents at other levels of government. Thus, after Ontario created its Premier's Council on Science and Technology in 1986 (now the Premier's Council on Economic Renewal), the other provinces and the federal and territorial governments followed suit, creating their own advisory boards. They did so not merely because this was a politically fashionable thing to do, but because science and technology were seen as critical features of economic development and job creation (Quebec already had its own science and technology council, and the Science Council of Canada dates from 1966).

This is a much different environment from the simple days when the National Research Council of Canada – through the Honorary and Advisory Committee on Scientific and Industrial Research –

was the sole standard-bearer for scientific advice to government.

All of these bodies are now active in promoting the use, application, and adoption of S&T to their respective citizens. They meet once a year at the National Forum of Science and Technology Advisory Councils to discuss issues of mutual concern.³³

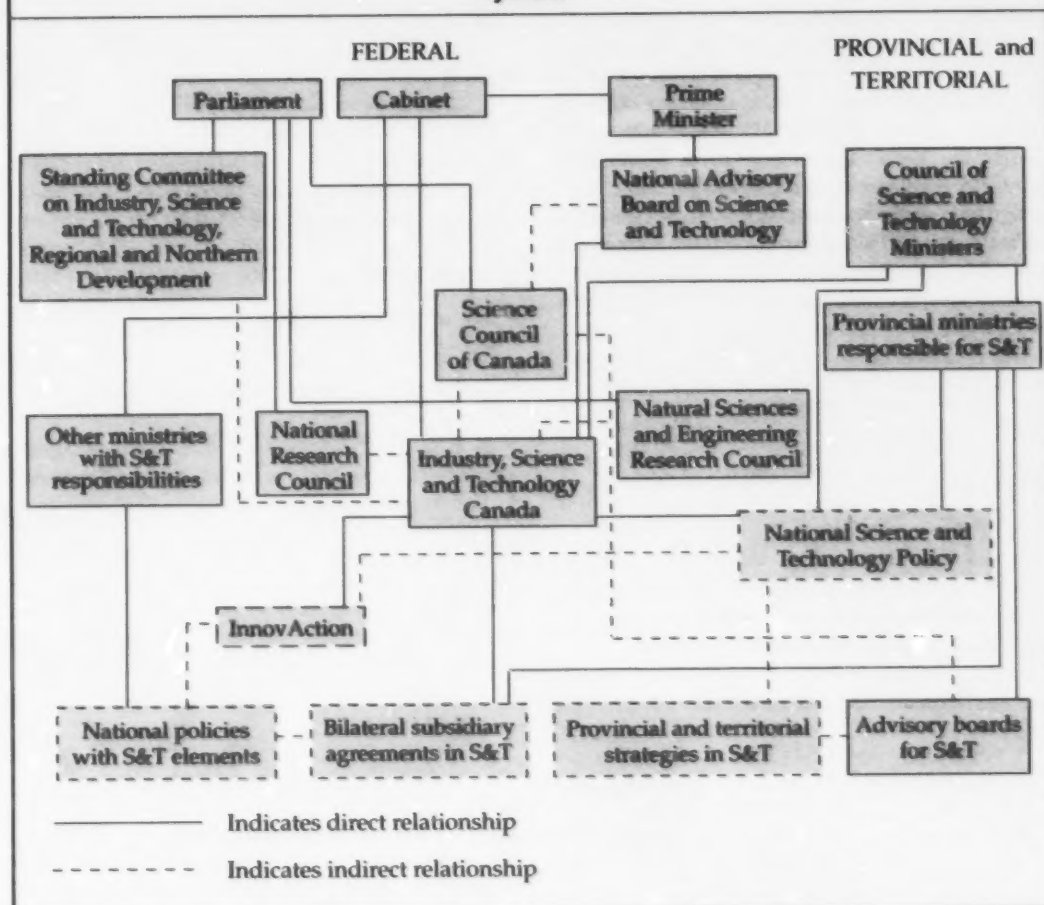
They are also in place to advise their respective governments on directions for S&T and as sounding boards for their governments. They can make full use of their knowledge of the local scientific and technical infrastructure to influence public policy directions, and it is in this capacity that they probably have their greatest impact.

For example, the Premier's Advisory Council on Science and Technology in British Columbia has created task forces to recommend policies relating to KAON, the Canadian Space Program, and hydrogen as an alternative fuel. It has also stimulated more technology-based innovation in the private sector. The Premier's Council on Science and Technology in Alberta has struck a number of subcommittees to explore ways to encourage the science and technology culture in the province and to look at the role of government support for S&T. The Newfoundland and Labrador Science and Technology Advisory Council has been developing sector-by-sector strategic plans to establish targets for technology-based industrial innovation, and to date has conducted reviews of the fish- and food-processing, agri-food, and information technology sectors. The newly restructured National Advisory Board on Science and Technology has a program involving six committees to review competitiveness, competitiveness of the resource industries, technology acquisition and diffusion, science and technology priorities, human resources and public awareness, and government procurement.

Individually, the provincial advisory bodies appear to have had some influence on the design of provincial S&T strategies. As a group, however, they have had limited success in catalysing partnerships and action by the Council of Science and Technology Ministers.

The federal, provincial, and territorial ministers responsible for science and technology signed Canada's first-ever National Science and Technology Policy in March 1987.³⁴ The policy was an attempt to lend some coherence to the national debate by focusing governments on finding solutions to such generic issues as: encouraging the commercialization of technology by promoting

Figure 1. Key Elements in Canada's National Science and Technology Policy System



technology diffusion and strengthening applied research and development; ensuring the availability of the necessary highly qualified people; encouraging the basic and applied R&D fundamental to Canada's scientific capability; and ensuring that science and technology become an integral part of Canadian culture.

The Council of Science and Technology Ministers (CSTM) has met regularly since the signature of the National Policy. In May 1991, the CSTM met in Saskatoon and released a "National Science and Technology Framework for Action," listing 18 measures the Council endorsed to enhance the deployment of S&T in Canada. Although the statement was not endorsed by the Quebec and Ontario governments, it is a good reflection of many of the issues that embody the S&T debate today.

The framework refers to the promotion of a science culture; the development of science resources; and the stimulation of innovation and of technology transfer, diffusion, and adoption in industry. However, because it does not purport to be an overall framework, but rather "a series of discrete actions stakeholders can take while work on a more comprehensive framework unfolds," the framework has failed to engage the imaginations of scientists, chief executive officers, and community and labour leaders.

The CSTM and its framework, unfortunately, have had considerable growing pains and are often seen by stakeholders as marginal to the national competitiveness debate. In 1991 the CSTM agreed to enhance its role by developing linkages with other pan-Canadian organizations such as the Council of Education Ministers, the

Canadian Labour Market and Productivity Centre, and the Canadian Council of Ministers of the Environment.

Of course, with the country beset by a major constitutional crisis, it has been difficult to orient national policy debates in areas other than legal and jurisdictional questions. In its recent statement *Science, Technology, and Constitutional Change*, the Science Council recognized the need to build federal-provincial cooperation and interprovincial linkages in S&T by making such bodies as the CSTM more effective participants in designing the national S&T agenda.³⁵

Here we have only highlighted the formal structures for science and technology policy. It would be a mistake to conclude that such formal mechanisms necessarily have an impact on changing Canada's infrastructure. Indeed, quite often, it is the informal networks and ad hoc initiatives that have greater impact in effecting change. A great deal of behind-the-scenes lobbying and networking go on. What professional lobbyists, trade associations, individual briefings to politicians, and other forms of "influence peddling" accomplish is always difficult to pinpoint. But that is the very nature of public policy.

The Surrogates for Industrial Research

Science in this country is yet in its infancy. Some day, when it has perhaps developed into a brawny giant, men may look back and ask about its early character and about the influences that moulded its youth.

— Henry T. Bovey, 1886³⁶

Designing the blueprint for the sound foundations of a knowledge-intensive economy also requires some skill at institution-building. Canada's early architects in this area were inspired by European and American models and they developed unique hybrid organizations. It was through the establishment of such institutions as the Geological Survey of Canada (1842), the Central Experimental Farm of Agriculture Canada (1886), and the Marine Biological Station (1899) that science (and applied science) began to flourish in Canada. With the establishment of the National Research Council in 1916 (and its labs in 1932), and the growth of university research facilities and provincial research organizations, Canada's investments in this intangible capital began to grow. Indeed, Canadian ingenuity and entrepreneurship led to many significant achieve-

ments. In engineering, for example, Canada's exceptional achievements include:

- development of the railway networks across the country;
- building of the St. Lawrence Seaway;
- DCH-2 Beaver;
- creation of the largest transmission network in the world;
- Alouette satellite;
- Bombardier snowmobile;
- James Bay very-high-voltage transmission system;
- Athabasca oil-sands development;
- Canadian nuclear power system;
- industrial installations of Polysar Ltd.³⁷

For economic reasons, government funding for industrial research was quite strong immediately before and after the Second World War. The industrial research infrastructure, however, remained poorly developed. For this reason, several commentators have seen the evolution of publicly funded research facilities as a surrogate for industrial research.³⁸

But, in fact, many public institutions did their job. The NRC, for example, created a demand for R&D in Canada with such instruments as the associate committee network (now disbanded), and the privatization of some research products through leading corporations such as Atomic Energy of Canada Ltd. and Polysar Ltd.

With the growth of the public research infrastructure, much of government policy has been geared to changing the behaviour of public institutions and employees to improve the "competitiveness" of the research infrastructure. Thus, one sees more and more attempts by decision makers to get value for money, as well as to make the public research apparatus more accountable and manageable from the perspective of an agenda that seeks to upgrade the national economy.

In the past decade or so, governments in Canada (and elsewhere) have taken numerous initiatives to create more coherence as well as efficiency in the physical infrastructure and to develop a more creative workforce.

The make-or-buy policy instituted in the early 1970s is a good example of the attempts made by the federal government to use public funding and facilities to upgrade industrial R&D capability.

Government procurement (now under examination by NABST) plays a critical role in acting as a "technology driver" for Canadian industrial competitiveness. In 1990-91, for example, the federal government spent \$8.5 billion to procure goods and services. A good deal of this was devoted to upgrading R&D in the private sector. (At \$229 million, the Canadian Space Agency accounted for over 55 per cent of this activity in R&D.) Some Canadian firms are, as a result, "chosen instruments" of the government. Spar Aerospace Ltd. received the most business from federal government procurement contracts - 127 contracts amounting to \$275 million. However, the Canadian Manufacturers' Association, for one, has stated that "government research cannot substitute for private-sector research."³⁹

Indeed, the Canadian government has become preoccupied with undertaking a more rigorous, ongoing evaluation of the relevance, quality, and regional distribution of federal intramural and contracted-out R&D activities. This evaluation begat the so-called Wright Task Force on Federal Policies and Programs for Technology Development,⁴⁰ which begat the Decision Framework for Science and Technology (a set of principles to coordinate the government's annual investments in S&T), which begat the NABST report on federal science and technology expenditures. This latest report, presented to the Prime Minister in 1990 and publicly released in 1991, concludes that:

fundamental changes are required in the organization and design of departments' intramural S&T activities and that a new management regime, one better suited to the unique nature of science and technology, needs to be established. More focused mandates, less bureaucratic and unproductive overhead, and improved management practices must be achieved.⁴¹

The report goes on to recommend five design elements of this new management framework: (1) an institute status, whereby each department is to transfer its S&T capability into one S&T institute; (2) contractual relationships between the institute and the department; (3) a revenue-dependency funding relationship whereby departmental program managers contract with the S&T institute; (4) a management structure for the institute; and (5) an evaluation regime for the institute.

The NABST committee, chaired by Pierre Lortie, former chief executive officer of Provigo, recognizes in its report the legitimate role of gov-

ernment labs to fulfil numerous categories of missions, and attempts to paint a broad, generic picture of how the federal research infrastructure ("a major national asset") can be made to perform better. It also attempts to deal with the severe morale problems afflicting employees of the federal R&D apparatus as a result of the ongoing scrutiny of public expenditures and concomitant downsizing in all areas.⁴²

A U.S. Congressional report on federal spending for infrastructure, including R&D, has argued for caution when examining the returns from such investments to the economy. As the study concludes,

spending for R&D that is primarily intended to support the missions of particular federal agencies is best evaluated on the basis of its contribution to the mission (and the perceived merit of the mission itself).... claims of substantial economic benefits beyond contributions to agency missions should be viewed sceptically and accepted only after specific cases and technologies are evaluated.⁴³

The Lortie report has had little visibility to date, although the government has given the Communications Research Centre institute status. One can also see the report's influences in the restructuring of the National Research Council (with its 1990-95 long-range plan), and other measures such as the dissolution of Canadian Patents and Development Limited, and the design of a framework for technology transfer from government laboratories for commercial applications.

This last initiative has been prepared by the Interdepartmental Group on Intellectual Property Management, a committee of more than 20 federal government departments and agencies whose function is "to identify technology transfer mechanisms needed to facilitate the fullest exploitation of government-sponsored R&D for economic, social and cultural benefits."⁴⁴

The group is developing a technology transfer "tool box" aimed at improving a company's capability to acquire and commercially exploit technology. This group is a welcome example of federal science-based departments and agencies developing an action-oriented agenda to deal with the many operational, administrative, legal, and technical hurdles confronting their management in attempting to transfer technology to the private sector. The success of these efforts can be measured in part by the numerous S&T alliances

now in place between federal agencies and other organizations representing over \$1 billion in expenditures.⁴⁵

Another recent example is the contract from Environment Canada's Wastewater Technology Centre in Burlington, Ontario, to RockCliffe Research Management Inc. to manage the commercialization of technology issuing from the labs of this world-renowned facility. Under the three-year pilot arrangement, the centre's employees, who specialize in research on industrial and municipal waste water treatment, will obtain a 20 per cent cut of any profits the lab makes selling its waste disposal technology.

Other experiments in new forms of institution-building include considerable attention to the links between public (and quasi-public) organizations and the private sector. Such models have been increasing domestically and globally. They take the form of interdisciplinary centres, excellence centres, cooperative industry-university centres, technology transfer centres, innovation centres, science parks, and so on.

One illustration of such experimentation, which appears to have been successful, is the Natural Sciences and Engineering Research Council's Industrial Research Chairs Program. The chairs program, created in 1984, was designed to help universities build on existing strengths, and to assist in the development of research efforts in fields for which there is an important industrial need. The program is funded jointly by NSERC, industry, and the host university. By September 1991, 85 chairs had been financed, with total commitments of \$75 million from NSERC and \$47 million from industry. The chairs cover technologies ranging from wood preservation and grain technology, to the management of technology and metallurgical process engineering.⁴⁶

The critical factor is that Canadian institution-building and infrastructure upgrading is keeping step with global developments in science and technology. This requires a great deal of adaptability and flexibility within a normally rigid bureaucratic system. As an examination of the key ingredients to the success of Western economies notes: "Growth is, of course, a form of change, and growth is impossible when change is not permitted. And *successful* change requires a large measure of freedom to experiment."⁴⁷

Embedding the Infrastructure

No other issue has received more play in the rhetoric (and initiatives) associated with a healthy infrastructure for scientific research, industrial innovation, and technology transfer and diffusion than the question of adequate supply of and demand for people.

Whether in a multinational corporation assessing the potential for bundling its core competencies, or in a community college trying to create a unique specialization, the issue is the same. Whether in a small firm trying to adjust to changes in automated techniques, or in a university attempting to create a new interdisciplinary team, the issue is one of motivated, creative individuals.

The past year has seen a renaissance of the "learning for a living" approach in virtually every facet of Canadian society. As our chapter "Education, Training, and Literacy" makes clear, a host of issues now face this country in its ability to attract, motivate, and train people in the skills required for the new economy.

Canada's higher education system has been buffeted by severe erosion of its purchasing power with resultant negative impact on teaching, training, and research mandates. Michael Porter pointed out the undervaluation of vocational and technical training in this country:

Occupational standards for skilled trades are poorly developed, reflecting a strong social and cultural bias toward university-educated, white-collar occupations. Technical and vocational schools – extensively used in many other countries to provide intensive skills training – are widely perceived to be "second best" in Canada.⁴⁸

These issues, and others, are being examined by the federal government in consultations as part of its Prosperity Initiative and, perhaps more importantly, have prompted action by the provincial governments as well.

Alberta's "Visions for the Nineties" action plan for education includes such targets as developing vocational programs to prepare students for tomorrow's job markets; improving science programs for all students and establishing specialized science and technology schools for students with special abilities; and making sure teachers keep up with current knowledge.

In Quebec, the Conseil du Patronat (the province's largest employers' group) has urged the government to set long-term goals in this area, including reducing illiteracy by 50 per cent, boosting the number of Quebecers over 15 who hold a high school diploma to 50 per cent from 38 per cent, and increasing the number of students registered in high school professional training programs by 300 per cent and in college programs by 50 per cent.

Innovative work is also under way to enhance the prestige of science, technology, and engineering as career choices. The Canada Scholarships Program, announced in 1988 and managed by the Association of Universities and Colleges of Canada, awards a minimum of 2500 scholarships annually to top Canadian students entering undergraduate studies in the natural sciences, engineering, and related disciplines. The program will be extended to include awards to technicians and technologists entering vocational schools and colleges. Canada Scholarships are divided about equally between men and women. Now in its fourth year, this program has evolved to include other initiatives, for instance, a "frontrunners" program in which present and past Canada Scholars volunteer to visit elementary and secondary schools and Cégeps to talk to students about science and technology; corporate awards that supplement the Canada Scholarships or establish new awards, including a Governor General's Award for Environmental Engineering funded by Du Pont Canada; and Canada Scholar Mentor Clubs designed to help scholars maintain their outstanding academic performance.³⁰

Attention is also being paid to the erosion of facilities for equipment and instrumentation – a key component of a nation's competitive advantage. As the brochure for a major international conference on equipping science held in Amsterdam in April 1992 underlines,

A key question facing policy-makers in the 1990s concerns how best to meet the demands of the scientific community for investment in modern equipment and facilities. The strategic significance of many areas of basic research for future industrial technology gives added urgency to this task.

Indeed, in the 1990 "Health of the Disciplines" reports produced for NSERC, a number of disciplines clearly targeted this issue as critical. The plant biology discipline report argues:

the replacement of ageing equipment, the need to apply new instrumentation and techniques and to bear the costs of accommodating experimental animals and plants are among the factors threatening the health of basic food science research in Canada.³¹

Upgrading facilities and instrumentation is one thing, but not being able to use them fully for lack of adequate infrastructure support (such as technical personnel and operating budgets) is another matter. The computing and information science field, for example, is facing this dilemma.³²

Issues of the adequate supply of and demand for qualified workers are critical. Just as the U.S. Congress is now examining the question of a "shortfall" in scientists and engineers, so too is there more serious re-examination in Canada of the issue. The chemists, engineers, and mathematicians, for example, have each produced systematic documentation of the questions surrounding supply and demand for their professions. To the extent that other countries have similar problems (particularly the United States), Canada can expect severe competition for its highly talented graduates.

The French have begun active recruiting campaigns for Canadian engineering and other graduates. Japanese companies, too, have intensified their recruitment campaigns on Canadian university campuses. (In 1990, for example, Toshiba succeeded in hiring seven Canadian university graduates in electrical engineering.)

These examples illustrate one of the effects of globalization on the research system. The higher education system will have some severe challenges to face as nations vie to attract talent. In order to prepare for this, some universities have developed guidelines. In the United States, for example, MIT has a series of principles and policies that will guide the university's international activities in such areas as access to research, licensing of patents, start-up companies, and visiting faculty, postdoctoral, and research scientists.

In Canada, there are indications that some institutions are taking a more proactive stance. In June 1991, the universities of York, Carleton, British Columbia, and Laval formed the Swedish Canadian Academic Foundation with the universities of Umeå, Uppsala, Linköping, and Stockholm in Sweden. The foundation will provide the organizational and financial basis for coordinating exchanges of faculty and students

among the participating institutions. In 1991, the Association of Universities and Colleges of Canada made public the results of a "globalization" survey among its 89 member institutions. The results provide a rich source of information about the degree of preparedness of Canada's higher education establishment in the new international context. For instance, one innovative initiative has been undertaken by a number of Canadian universities that banded together with support from the Japan Science and Technology Fund to offer co-op students semesters in Japanese industries. The three-year Japan co-op placement program is offered to qualified undergraduate students at the universities of Waterloo, Simon Fraser, Victoria, and Sherbrooke.

The United States has always been a major draw for Canadian talent, and fears of a "brain drain" from Canada have been with us since the years following the Second World War when massive reconstruction efforts offered opportunities for Canadian graduates abroad. The issue has recently resurfaced with the Americans projecting a shortfall of 640 000 scientists and engineers to the year 2000. When Canadian Richard Taylor (the Stanford professor and winner of the Nobel Prize for physics in 1990) was interviewed on this issue in October 1991, he slammed the research environment in Canada. Arguing that Canadian scientists are "leaking out," he went on to note that "there's more Canadian content in the U.S. scientific establishment than on the television in my hotel room here (in Canada)."⁵²

But the issue is a double-edged one. Many foreign postdoctoral fellows who were funded through the NRC over the past half-century have had prestigious careers in their home countries. In some cases, they have become senior corporate managers in large global firms – often an intangible asset for Canadian companies wishing to conduct business with these firms. And Canadian graduate D. Allan Bromley, President Bush's chief science adviser, has no doubt had a considerable impact on the Canadian government's funding decision regarding KAON and on the U.S. contribution to Canadian-initiated international science projects.

In the corporate world, considerable attention is paid to skills development and to appropriate linkages with the educational system. This has taken on some urgency, particularly where there are gaps in the requisite skills. But in many instances, the market in Canada is just not large enough to produce all the necessary expertise.

Quebec, for example, has instituted a two-year tax holiday for foreign researchers hired by Quebec firms. Other tactics to capture "knowledge workers" range from establishment of a new R&D lab (such as Teleglobe's \$200 million five-year investment announced in October 1991), to increased consultancy work, to enhanced use of unique research facilities on the university campus, to sponsorship of industrial chairs and fellowships (e.g., the pharmaceutical industry funded 130 fellowships in Canadian universities in 1991).

An Eroding Base?

There ought to be a *fin de siècle* air of excitement for the newly fledged science postdoc these days; after all, he or she will hit the most productive years of scientific life not merely in a new century but in a new millennium. The horizons should seem limitless. Except....

– *Science*⁵³

Numerous pressures confront those who conduct scientific research. Adequate and sustained financing is obviously critical. Moreover, it is a difficulty the scientific community faces worldwide. Over the past year, the British scientific community has recognized the need to undergo revitalization – so much so that the journal *Nature* has produced a Manifesto for British Science.⁵⁴

In November 1991 the Organisation for Economic Co-operation and Development held a special meeting of the Heads of Research Councils from industrialized countries to explore how the science system could be better managed. One of the conclusions of this and subsequent meetings of the OECD's Group on Scientific and University Research was that there is a tendency among OECD governments generally not to pay

sufficient attention to the time and structural adjustments involved in building research capabilities of adequate size and quality, especially in cases where new multidisciplinary fields have to be developed.⁵⁵

The burgeoning environmental research field is one such example.

In the United States, a number of organizations have developed insights into the challenges facing the research enterprise. The president-elect of the American Association for the Advancement of Science, Leon Lederman, wrote a controversial report in January 1991 arguing that university research was in serious trouble.⁵⁶ The Office of Technology Assessment has conducted a detailed

examination of the federal research system.⁵⁷ The journal *Science* has summarized career trends for the 1990s.⁵⁸

In Japan, government and industry are concerned about lagging behind Europe and the United States with respect to their levels of basic research.⁵⁹ The Japanese (often considered poor supporters of basic research, especially in the university system) have formed a powerful pressure group within the ruling Liberal Democratic Party. This special committee reinforces the importance of maintaining the basic research base and international research cooperation.

In these and other cases, the amount of public money being spent on science is as important as the way in which it is spent. This is not an insignificant issue in Canada. The Medical Research Council of Canada, for example, has taken the matter to heart, and under its new president, Henry Friesen, has launched a major review of Canadian medical research designed to link a national medical research strategy to Canada's economic and health care needs.⁶⁰ Similarly, the Natural Sciences and Engineering Research Council and the Social Sciences and Humanities Research Council have both engaged in strategic long-term planning to deal with the new context for research.

Funds are also available to foster research in the provinces. Quebec has a comprehensive granting program (in the natural, medical, and agricultural sciences). Ontario has a Centres of Excellence Program designed to foster collaborative research. The Science Council of British Columbia has several unique S&T funding programs in support of researchers. The Alberta government has established the Heritage Foundation for Medical Research.

The Royal Society of Canada raised a number of pressing funding issues in its report *Realizing the Potential: A Strategy for University Research in Canada* in February 1991. Among its recommendations regarding direct funding of research at universities, the society suggested as a guiding principle for the research councils that approximately 30 per cent of those eligible to apply for research grants are worthy of support at internationally competitive funding levels (with special consideration to beginning researchers), and that a further 20 per cent are worthy of support at perhaps a lesser level (the base of university research), these being funded through a reformed system of "block grants" to the universities.

Among its other recommendations, the report touched on the funding of multidisciplinary and collaborative research, increased funding for the social sciences and humanities, the indirect costs of research, support for the next generation of Canadian researchers, responsibilities of the universities, and the need for ongoing coordination and evaluation. This report has resulted in some debate, but its recommendations warrant careful examination. The Canadian Federation of the Humanities put it this way: "The Royal Society's Report has thrown down the glove to a lot of family members; it is a major contribution to making something of our talents."⁶¹

And there are other challenges. They include the greying of the academic community, the rise in the cost of research, the increase in university-industry linkages, big versus little science, the Established Programs Financing transfer issue (discussed in the "Education, Training, and Literacy" chapter), multidisciplinary, and, of course, the effects of globalization on all aspects of higher education.

Ultimately, because they are the prime funders of basic research, governments in Canada will have to assist our research institutions in meeting these challenges. It will mean better government appreciation of how science in this country is conducted. It will mean that:

governments should forswear hasty and ill-considered decision-making touching science and research. Snap decisions distract researchers from what they do best, interrupt careers in random ways and (when made apparently on whim) demean the advisory process which is, at present, the only means at the government's disposal for winning the research community's consent to its decisions.⁶²

This is a two-way street, however. For the scientific community, it will mean developing a more relevant and politically astute public awareness campaign that demonstrates the need for a robust scientific infrastructure.

On the Horizon

Nowadays, the competitive strength of a research entity in the international marketplace depends as much on the funding policy of its government as on its own innate scientific excellence. National funding bodies are simply not willing to underwrite the inevitable wastage of a system of outright scientific "laissez

faire," and introduce various elements of "coordination" to economise on their science budgets.

- John Ziman⁶¹

Canada's science and technology infrastructure is up against many of the challenges that other countries are facing. In Europe, Germany is struggling with enormous financial, administrative, and personnel difficulties in absorbing the scientific excellence of the former East German republic. The United Kingdom is reconsidering funding levels for its participation in international collaborative research projects. The Dutch are re-examining their technology policy and assessing their strengths and weaknesses from a global perspective.

The American scientific community is debating the pros and cons of setting priorities to assist Congress and the executive branch in their future funding decisions for R&D. The Americans are also clearly concerned over the erosion of their technological leadership. U.S. firms have identified management practices (and, in particular, short time horizons and management by numbers rather than strategic vision) as their biggest weakness in meeting competitive challenges. Indeed, in a nationwide poll conducted by the private sector Council on Competitiveness, Americans cited loss of key industries and technological leadership as the second most important economic problem ahead of the deficit, inflation, and federal taxes. Only unemployment and loss of job opportunities rated higher.⁶²

The Japanese are focusing on core businesses. A 1991 survey of 100 company presidents identified the meeting of customer needs and investment in technology and research as the most important areas of concentration. In contrast, a survey of Canada's corporate sector put technology management practices and lack of skilled R&D personnel at the bottom of the list of adverse factors affecting investment in R&D.⁶³

It is clear from numerous examinations of the issues affecting Canada's S&T infrastructure that the management issue is both problematic and difficult to quantify. From the World Economic Forum survey to the Porter study, from the Economic Council's project on competitiveness to the Science Council's sectoral technology strategy series, "strategy and vision" are cited as the country's weakest links in making the transition from a mindset of resource management to one of resource creation. Management attitudes toward

technology, leadership, competitive strategy, and product marketing strategy will have to be addressed more systematically if change is to come about.

Another looming issue is the impact of globalization on science and technology. International issues will have significant repercussions on how nations upgrade their infrastructures. The United States is concerned about its international credibility as a reliable partner in collaborative S&T.⁶⁴ The Japanese are developing new international experiments such as the Intelligent Manufacturing Systems Program and the Human Frontier Science Program designed to complement and strengthen their national infrastructure.⁶⁵ The Europeans are strengthening their collective R&D capability through the newest five-year Framework Programme for R&D.

Canada and its scientists, engineers, mathematicians, and other knowledge professionals, while already part of these developments, have to think carefully about being positioned to reap the benefits of these and other international opportunities. This will require considerable attention to international activities affecting our academic, business, labour, and government sectors. In some instances, debate and action are in progress; in others, a debate has yet to begin.

In several quarters, it is apparent that meeting the challenges of internationalization will also mean upgrading "technology capacity" in local regions. The work under way to strengthen the S&T infrastructures in the municipal, provincial, and interprovincial domains will clearly contribute to Canada's competitive capabilities. This trend is taking diverse forms: metropolitan technology councils, locally designed technology and industrial strategies, outreach arrangements with other subnational entities (e.g., twinning agreements, bilateral exchanges, and so on). The Science Council's work on "technology engines" has led to considerable efforts in Canada's regions to bootstrap our S&T infrastructure.⁶⁶ One can expect an increase in such initiatives as local communities upgrade their infrastructures to address the competitive pressures from abroad. Marshall Cohen, president and chief executive officer of Molson Companies Ltd., has summarized the issue well:

The most appropriate political frame of reference for developing clusters of excellence may be one that combines an overarching arrangement...with smaller but more active

regional and local entities. The important point about these regional economies is that they will look outward to the global economy, rather than to national capitals, as the main force in shaping their economies.⁶⁶

Conclusion

This section has focused on selected areas of infrastructure important to scientific and technological development. It has omitted extensive commentary on other critical areas of infrastructure such as regional development, regulation, rewards, international technology-transfer mechanisms, venture capital, and the environment for risk, not because these are unimportant, but simply because time and space would not allow us to develop these themes further.

It has also left discussion of the most important element of infrastructure – education and its support institutions – to another section. As Louis Berlinguet, president of the Conseil de la science et de la technologie du Québec warns,

These last few years have seen a substantial increase in infrastructure expenditures, as evidenced by the growing numbers of research centres and laboratories...and the many government measures to assist R&D. But to be effective, these measures must be accompanied by an even greater increase in the numbers of highly qualified personnel ready and able to contribute to the processes of technological innovation [Translation].⁷⁰

Lessons to be learned from recent events and opinions related to Canada's S&T infrastructures are:

- Maintenance and upgrading of our country's national assets in scientific research and industrial innovation are essential to national prosperity.
- The national debate is consumed by questions relating to relevance, efficiency, accountability, and coherence. As a result, development of the infrastructure is seen by many only as a means of improving our national economy and international linkages.
- The environment for science must be upgraded to get Canada's science base out of the quagmire. The opportunity exists to turn things around in the new context for Canadian competitiveness.
- The scientific and technical communities, as well as the policy brokers, have a responsibility to provide clear communication and argument in building the national vision required for our country.
- Funding will help in some cases. In others, innovation in designing infrastructure will be required. In the end, the right signals have to be provided to allow scientists, engineers, mathematicians, policy makers, entrepreneurs, economists, industrialists, and other stakeholders to contribute fully in designing the architecture for national prosperity.

Ultimately, a better appreciation of the differences between how science is conducted, and how industrial innovation takes place, is required. Innovation is not a simple process of development from fundamental research, through applied science and technological development, to the design and manufacture of new products or processes. It is much more complex than that. A more sophisticated understanding of the distinction between science and innovation would greatly benefit both, and might considerably improve the design and coherence of framework policies for Canada's scientific and technical infrastructure.

For this, the bickering will have to stop. The mudslinging and cynicism that have prevailed in the past with government blaming industry, industry blaming government and academe, and labour being marginalized in the national debate, have been counterproductive. A more constructive dialogue will have to be fashioned if science and technology are to take their rightful place as vital components of a new economy.

Notes

1. J.C. Polanyi, "Science's horse must go before technology's cart," *The Globe and Mail*, 23 April 1990.
2. K. Pavitt, "What Makes Basic Research Economically Useful?" *Research Policy* 20 (April 1991): 118.
3. "Science: Wielding the Axe," *The Economist* (6 February 1991).
4. Gordon MacNabb, cited in "Science in Canada: Canada's Changing Times," *Nature* (23 June 1988): 6175.
5. Council of Maritime Premiers, *Challenge and Opportunity: A Discussion Paper on Maritime Economic Integration* (Halifax, May 1991), 23. The Minister's Advisory Board on Science and Technology (New Brunswick), the Coun-

- cil of Applied Science and Technology (Nova Scotia), and the Council on Science and Technology (Prince Edward Island) were involved in preparing this joint report.
6. With apologies to Robert Gilpin. See his "Science Policy for What: The Uniqueness of the Canadian Situation," paper for discussion at the Conference on Science Policy and Political Science, Science Council of Canada, Ottawa, 18-19 March 1971.
 7. Derek J. deSolla Price, "The Scientific Foundations of Science Policy," *Nature* (17 April 1965): 237.
 8. This particular phrase found currency during the negotiation of Canada's first-ever National Science and Technology Policy signed in March 1987. The phrase was inspired by a speech given in 1985 by Neil Kinnock, the leader of the Labour Party in the United Kingdom. See N. Kinnock, "Putting Science to Work: A Strategy for the Future," *Science and Public Policy* 12(6) (1985): 299-305.
 9. There is considerable literature now available on this subject, including Edwin Mansfield, "The Social Rate of Return from Academic Research," *Research Policy* 20 (February 1991): 1-12, and Congress of the United States, Office of Technology Assessment, *Federally-Funded Research: Decisions for a Decade* (Washington, D.C.: Superintendent of Documents, 1991). See also Genevieve J. Knezo, *A Bibliography on Measuring the Economic Benefits of Federally Supported Research* (Washington, D.C.: Congressional Research Service, Library of Congress, 25 February 1991).
 10. See K. Pavitt, "What Makes Basic Research Economically Useful?" *Research Policy* 20 (April 1991): 109-119, for a general discussion of this issue. On the Canadian front, the recent spate of reports on the role and function of government research facilities and their "privatization" serves to indicate that Canadian policy makers are seeing the link between sound infrastructure and economic competitiveness. See *Revitalizing Science and Technology in the Government of Canada: The Report of the Committee on Federal Science and Technology Expenditures* (Ottawa: National Advisory Board on Science and Technology, 1990).
 11. Canadian expenditures in R&D have come a long way in a short time. It may be useful to remind readers that total outlay by government for research and other scientific activity was \$6 million in 1938, a figure that jumped to \$40 million in 1947 following the Second World War. Expenditures in 1947 for grants and scholarships for research in the natural and physical sciences amounted to \$1 million, including provision of new facilities for nuclear research.
 12. *Total Spending on Research and Development in Canada, 1971 to 1991*, Service Bulletin 15(3) (Ottawa: Statistics Canada, July 1991).
 13. Conference Board of Canada, *R and D Outlook 1992*, 8th ed. (Ottawa, November 1991). It is important to understand that while real industrial R&D expenditures are increasing, industrial R&D expenditures as a percentage of GDP have been falling from 0.78 per cent in 1986 to 0.74 per cent in 1989. Much work is under way to try to explain the structural reasons for this decline, including the Science Council's sectoral technology strategy project covering 15 industries. See also M.E. Porter and the Monitor Company, *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Business Council on National Issues and Minister of Supply and Services, 1991).
 14. *Focus 2000: Report of the Task Force on Technology and Canadian Business* (Ottawa: Canadian Chamber of Commerce, August 1988), vii.
 15. D. Vice, "R&D must focus on markets," *The Globe and Mail*, 18 June 1991.
 16. None have put it more bluntly than the Prime Minister himself when he said, "These are extremely difficult issues to remedy; their roots go deep into our industrial and financial structures. Despite a blitzkrieg of governmental initiatives, both federal and provincial, there has been no substantial improvement in this area by the private sector." Notes for an address to the Progressive Conservative Party's General Meeting, Ottawa, 25 August 1989.
 17. Denzil Doyle, "Easing Venture Capital's Way," *The Ottawa Citizen*, 30 April 1991. On this last point, the president of the Canadian Manufacturers' Association, Jack MacMillan, indicates that the only way to show leadership (in making Canadian firms globally competitive) is to change the people at the top. As Mr. MacMillan noted in an interview published in *The Financial Times of Canada* on 29 July 1991, "The successful companies that have really changed their mindset have done it with different men at the top. There's a lot of new management running companies today that were not with the company five years ago. I'm not sure that's the case in bureaucracy. I'm not sure that's the case in the labor movement."
 18. If we are to believe a 1991 United Nations survey, Canada is the second most desirable nation on earth in which to live (after Japan), though Canada's record on widening income gaps between rich and poor is less than desirable. See United Nations Development Programme, *Human Development Report 1991* (New York: Oxford University Press, 1991).
 19. "Science in Canada: Canada's Changing Times," *Nature* (23 June 1988): 719.
 20. World Bank, *World Development Report 1991: The Challenge of Development* (New York: Oxford University Press, 1991), 6.
 21. Robert B. Reich, "Restricting Access to U.S. Research Would Be Nonsensical," *Nikkei Weekly* (20 July 1991).
 22. *A Science Policy for Canada: Report of the Senate Special Committee on Science Policy*, vol. 1, *A Critical Review: Past and Present* (Ottawa: Information Canada, 1970), 284.
 23. *Science and Technology, Innovation and National Prosperity: The Need for Canada to Change Course*, Report of the National Advisory Board on Science and Technology, presented to the Prime Minister of Canada (Ottawa, April 1991).
 24. The precedents for these arguments can be found in several Science Council reports, notably *Canadian Industrial Development: Some Policy Directions*, Report 37, 1984; and Guy P. Steed, *Not a Long Shot: Canadian Industrial Science and Technology Policy*, Background Study 55, 1989. Also see Canadian Institute for Advanced Research, *Innovation and Canada's Prosperity: The Transforming Power of Science, Engineering and Technology* (Toronto, 1988).

25. Readers may recall that Senator Maurice Lamontagne in his pioneering study on science policy in Canada had originally recommended a target of 2.5 per cent GERD to GDP ratio for 1980. He subsequently revised this figure to 1.5 per cent for 1982. See *A Science Policy for Canada: Report of the Special Committee of the Senate on Science Policy*, vol. 4, *Progress and Unfinished Business* (Ottawa, 1977). Fifteen years later, we're still talking targets, with little progress to show. In fact, Canada has never been close to 1.5 per cent despite the fact that provincial first ministers and territorial government leaders have endorsed a target of 2.5 per cent (Lamontagne's original target) by the year 2000.
26. *Selected Science and Technology Statistics 1991* (Ottawa: Industry, Science and Technology Canada, 1992), 20.
27. The 3 per cent cap did not apply to the 1991-92 fiscal year, but takes effect in fiscal year 1992-93. The federal granting councils saw their total budgets increase by 5.3 per cent for NSERC (to \$428 million), by 3.7 per cent for MRC (to \$230 million) and by 8.3 per cent for SSHRC (to \$97.6 million). In addition, the budget extended by three years the freeze on per capita transfers under the Established Programs Financing arrangements between the federal and provincial governments. The extension of the freeze to 1994-95 will have an impact on the ability of the provincial governments to support postsecondary education.
28. R&D is only one element of an activity called innovation, a creative process that rests on capabilities that range from research and development to engineering and design, tooling, manufacturing, and marketing. See Science Council of Canada, Industrial Policies Committee, *Hard Times, Hard Choices: Technology and the Balance of Payments*, Statement (Ottawa: Minister of Supply and Services, November 1981), 58.
29. Canadian Institute for Advanced Research, *Economic Growth: Science and Technology and Institutional Change in the Global Economy*, CIAR Publication No. 4 (Toronto, June 1991), 215.
30. See Chapter 7 of the 1991 federal budget for these arguments related to R&D. As the chapter notes: "Our private-sector R&D effort is particularly weak. Explanations include our resource-oriented industrial structure, a relatively high degree of foreign ownership and the small size of most Canadian firms. Nevertheless, a number of major Canadian industrial sectors perform substantially less R&D than their competitors abroad. Our R&D weakness may be hurting our productivity performance." *The Budget*, tabled in the House of Commons by the Honourable Michael H. Wilson, Minister of Finance, 26 February 1991, 138.
31. (Original quote: (La) valeur ajoutée dépend dans une large mesure de notre capacité d'avoir accès à l'information pertinente et de gérer cette information en recourant aux toutes dernières technologies. C'est ça l'avenir.) "Our Economy: State of Emergency," speech by Gérald Tremblay to the Convention of the Professional Corporation of Industrial Relations Counsellors of Quebec, Montréal, 10 September 1991.
32. However, the Senate decision may yet have negative repercussions on space science. The question of whether the United States is a reliable partner in scientific and technological collaboration has been usefully addressed in a report issued by the Carnegie Commission on Science, Technology and Government. Alexander Keynan, *The United States as a Partner in Scientific and Technological Cooperation: Some Perspectives from Across the Atlantic*, A Consultant Report (New York, June 1991).
33. The first three meetings were held in Halifax, Edmonton, and Victoria. The Halifax meeting published *The Halifax Declaration: A Call to Action*, A Report of the National Forum of Science and Technology Advisory Councils, in August 1989; it identified the following issues for common action: national expenditures on R&D, national awareness, human resources, enhancing science-based industrial innovation, and Canadian ownership. In 1990 the Edmonton meeting produced *The Edmonton Declaration: Accepting the Challenge*, A Report of Forum Proceedings, which expanded on some of the issues from the Halifax gathering. The Victoria meeting of 1991 resulted in *Building the Culture: Sharing the Experience*, which reviewed education and awareness, finance and measurements, and technology transfer and commercialization questions.
34. The policy had been preceded by a National Science and Technology Policy Forum organized by the Science Council of Canada in June 1986 in Winnipeg. See Science Council of Canada, *The National Conference on Science and Technology Policy* (Ottawa, November 1986). For a history of the national policy and how it came about, see Paul Dufour and Yves Gingras, "Development of Canadian Science and Technology Policy," *Science and Public Policy* 15(1) (1988): 13-18; or Dufour and Gingras, "Le Fédéralisme coopératif et la politique nationale des sciences et de la technologie," *Interface* (November/December 1988): 18-22.
35. Science Council of Canada, *Science, Technology, and Constitutional Change* (Ottawa, Ministry of Supply and Services, 1991). One suggestion for strengthening the dialogue in this country is to develop annual "S&T Outlook" conferences that would bring to the table government decision makers, the financial community, and the scientific and industrial research communities to assess the health of, and outlook for, S&T in Canada, particularly its weakest link - financing. The American Association for the Advancement of Science has been holding such annual symposiums for over 15 years now with apparent success in getting Congress, the Senate, and the White House to take action on critical funding issues. While the Canadian situation is slightly different, such an event could strengthen communication among the various camps supporting science in this country and assist their attempts to convey clear messages to the members of Parliament, Cabinet ministers, parliamentary committees, CEOs, and higher education officials who must understand the issues. Quebec's Association des directeurs de recherche industrielle and the Association des administrateurs de recherche universitaire cosponsored such a conference on R&D financing in Montréal in November 1991.
36. Henry T. Bovey, "The Progress of Science in Canada," lecture delivered to the St. Paul's YMCA, Montréal, 22 February 1886.
37. Engineering Centennial Board, 1987.

38. See Canadian Institute for Advanced Research, *Innovation and Canada's Prosperity: The Transforming Power of Science, Engineering and Technology* (Toronto, October 1988).
39. Canadian Manufacturers' Association, *The Aggressive Economy: Daring to Compete* (Ottawa, June 1989), 3-9.
40. Ministry of State for Science and Technology, *Report of the Task Force on Federal Policies and Programs for Technology Development* (Ottawa: Minister of Supply and Services), 1984.
41. National Advisory Board on Science and Technology, *Revitalizing Science and Technology in the Government of Canada: The Report of the Committee on Federal Science and Technology Expenditures* (Ottawa, November 1990).
42. For a statement on the role of the federal laboratories and their employees, see Professional Institute of the Public Service of Canada, *The Essential Role of Federal Scientists and Engineers: Their Role in the National Economy* (Ottawa, January 1988).
43. Congress of the United States, Congressional Budget Office, *How Federal Spending for Infrastructure and Other Public Investments Affects the Economy* (Washington, D.C., July 1991), 101.
44. IP Group, *Framework for Technology Transfer from Government Laboratories for Commercial Applications* (Ottawa: Industry, Science and Technology Canada, March 1991), 1.
45. Industry, Science and Technology Canada, "Federal Science and Technology Alliances Report," draft, Ottawa, 9 December 1991.
46. See the September 1991 issue of *R&D Bulletin* for a fuller description.
47. N. Rosenberg and L.E. Birdzell, Jr., *How the West Grew Rich: The Economic Transformation of the Industrial World* (New York: Basic Books, Inc., 1986), 34.
48. M.E. Porter and the Monitor Company, *Canada at the Crossroads: The Reality of a New Competitive Environment*, summary (Ottawa: Business Council on National Issues and Minister of Supply and Services, October 1991), 49-50.
49. See Industry, Science and Technology Canada, *Canada Scholarships Program 1990-91 Report Card* (Ottawa, 1991).
50. "Health of Plant Biology as a Discipline," submitted by the Plant Biology Grant Selection Committee, Natural Sciences and Engineering Research Council, Ottawa, April 1990.
51. Health of the Discipline Report for Computing and Information Sciences, Natural Sciences and Engineering Research Council, Ottawa, March 1991.
52. Shelley Page, "The Brain Drain," *The Ottawa Citizen*, 20 October 1991.
53. Constance Holden, "Career Trends for the '90s," *Science* (24 May 1991): 1110.
54. "Nature's Manifesto for British Science," *Nature* (12 September 1991): 105-112.
55. Organisation for Economic Co-operation and Development, "Managing the Science System in a New Context," draft discussion paper, DSTI/STP/RD (91) 5, 18 October 1991.
56. "Science: The End of the Frontier?" A report from Leon M. Lederman, president-elect, to the board of governors of the American Association for the Advancement of Science, January 1991.
57. Congress of the United States, Office of Technology Assessment, *Federally-Funded Research: Decisions for a Decade* (Washington, D.C., 1991).
58. "Special Report: Science Careers, A Guide to the 90s for New and Future Scientists," *Science* (24 May 1991): 1107-1150.
59. Japan, Science and Technology Agency, *White Paper on Science and Technology 1991* (Tokyo, September 1991).
60. See *Research Money* (3 December 1991): 1.
61. "The Royal Society's Gloves," *Bulletin of the Canadian Federation of the Humanities* 14(1) (Winter 1991).
62. "Nature's Manifesto for British Science," *Nature* (12 September 1991): 107.
63. John Ziman, "Does the collectivisation of science mean that academic research ought to be organised internationally?" Paper presented to Sociology of Sciences Yearbook Conference, What Is International in Science? Abisko, Sweden, 30 May 1991.
64. Council on Competitiveness, *Looking for Leadership: The Public, Competitiveness and Campaign '92* (Washington, D.C., 1992).
65. Conference Board of Canada, *R and D Outlook 1992*, 8th ed. (Ottawa, November 1991).
66. For a discussion of this issue, see Alexander Keynan, *The United States as a Partner in Scientific and Technological Cooperation: Some Perspectives from Across the Atlantic*, A Consultant Report (New York, June 1991).
67. See George Heaton, Jr., *International R&D Cooperation: Lessons from the Intelligent Manufacturing Systems Proposal*, The Manufacturing Forum, Discussion Paper No. 2 (Washington, D.C., 1991).
68. See "Guidelines for the Organization of Local Technology Engine Workshops and the Integration of S&T into Strategic Economic Development Planning," manuscript report (Ottawa: Science Council of Canada, July 1991).
69. Marshall Cohen, "Regional Economies Could Open Pathways to Global Liberalization," *The Financial Post*, 17 June 1991.
70. (Original quote: Ces dernières années, on a beaucoup accru les dépenses d'infrastructure comme en témoignent la multiplication des centres et des laboratoires de recherche...et les nombreuses mesures gouvernementales d'aide à la recherche et du développement. Mais ces mesures, pour être pleinement efficaces, doivent être accompagnées d'une augmentation encore plus grande d'une main-d'oeuvre de plus en plus qualifiée et prête à contribuer aux processus d'innovation technologiques.) *Le Devoir*, 12 October 1991.

4. Environmental Impacts of Science and Technology

Slowly but surely we in Canada are embracing the notion of sustainable development. It is against that yardstick that decision makers are increasingly measuring the impacts of policies, priorities, and spending directed at science and technology, trying more and more to ensure that today's actions do not compromise the quality and resilience of our environment for future generations.

Sustainable development is seen as the ultimate determining factor in our ability to achieve the global environmental conditions we value and need. In so doing it links domestic Canadian activities and values with those of other nations and recognizes the interdependencies of nations and ecosystems. The notion of sustainability is setting new parameters for private and public sector policies, priorities, and spending directed at the development and use of science and technology today.

For some, sustainable development implies that there will be integrated consideration of environmental and economic factors when policies are made, thereby balancing the hitherto environmentally unsustainable drive for economic growth with a keen sense of responsibility for the scrupulous stewardship of the environment. Some others see sustainable development as precluding economic growth. For a third group, sustainable development implies that the environment can be preserved without compromising economic growth and that, in fact, ensuring environmentally sustainable economic development requires the technological advance and wealth that is generated by continued economic growth.

The debate is seizing citizens, social scientists, and environmentalists worldwide, and in the process traditional economic models are being challenged and changed. Wherever one sits in the debate, however, the integrity and quality of the environment is taken as an essential objective. Despite the wide range of views, there is evidence that many elements of the philosophy of "sustainable development," including the integration of long-term environmental considerations into all aspects of a company's business, are being taken seriously by industry and government in Canada. Some businesses have adopted the attitude that helping to maintain a healthy environment is simply good business practice.

The sustainable development challenge has been recognized globally.¹ Following from the work of the World Commission on Environment and Development (the Brundtland Commission),² there is broad recognition of the threat to the quality of life and even the survival of humanity if the environment is not integrated into our thinking about the economy and competitiveness. Countries around the world are currently preparing for the United Nations Conference on Environment and Development (or Earth Summit) to be held in Rio de Janeiro in June 1992. The summit is expected to attract more than 100 presidents, prime ministers, and other national leaders in a quest to sign an "Earth Charter" of environmental and economic principles and in an attempt to develop an agenda for achieving sustainable development in the 21st century ("Agenda 21"). It is not yet clear, however, that domestic Canadian actions and attitudes are developing in accordance with this global vision.

Science and technology affect much more than our physical environment; they have profound social, cultural, and economic effects as well, touching on every aspect of our lives. Even confining this discussion to some of the broad environmental impacts of S&T is no easy task, and we hope that what follows will at least set the stage for more focused analysis in future reports. Here, we will concentrate not on science and technology themselves, but on the way they are deployed and managed in relation to what we perceive to be Canadian environmental values and principles.

Progress?

The year 1991 brought many initiatives from all sectors of society, including governments, business people, academics, consumers, and others.

The \$3 billion Green Plan is the prime vehicle for the federal government's six-year national environment strategy.³ Since its December 1990 unveiling there have been announcements of numerous multimillion-dollar initiatives with potentially sweeping implications for the development and use of science and technology (see box). These range from clean-up technology programs such as a \$100 million restoration of British Columbia's Fraser River, to research efforts such as a \$25 million study of ozone layer

depletion over the Arctic, to preventive technology programs, including a \$100 million program to accelerate development and demonstration of commercially viable pollution abatement technologies and a \$50 million fund to promote multidisciplinary ecosystem research and research training. An extensive assessment is premature; many of the six-year initiatives are still in development or in early phases. In general, however, the individual initiatives have been well received despite continuing questions. Some of the questions relate to the lack of a clear overarching conceptual framework, to the integration of what appear to be piecemeal efforts, and to the feasibility of the rate of change for industry.

New environmental assessment legislation, another critical feature of the Green Plan, also received attention in 1991. A comprehensive package of reforms to the federal environmental review process was first introduced in Parliament in June 1990. As part of the package, the federal government made commitments to amend project environmental assessment legislation and to assess the environmental implications of all new policy and program submissions coming before Cabinet for approval. But before these actions could be taken, a method to perform environmental assessment reviews of policies was required. As of late 1991, a House of Commons legislative committee was conducting a clause-by-clause review of an environmental assessment bill. Assessment of progress on the legislative front must await a future review.

In 1991, the federal government also announced new regulations, first proposed in 1990, to virtually eliminate the discharge of furans and dioxins in pulp mill effluent.⁴ The new regulations are part of the government's promise made in the Green Plan to beef up enforcement of the Canadian Environmental Protection Act. The federal government expects all companies to comply with the new pulp mill regulations by the start of 1994.

Some federal initiatives to foster sustainable development were announced prior to the Green Plan. For example, the Department of Fisheries and Oceans planned to spend \$38 million in 1991-92 to support the Atlantic Fisheries Adjustment Program, a key element of which is dedicated to scientific research geared to rebuilding stocks of northern cod.⁵

Provincial and territorial governments have also responded to the sustainable development challenge, particularly with initiatives in the area

of environmental regulations. For example, in September 1991 Ontario announced that it will toughen a set of rules that was established six years ago to curb pollution, but never used. The new version of the regulations will also restrict air pollution and ban some industrial chemicals. The regulations will come into effect gradually, but at the time of the announcement Ontario did not release a timetable. In September 1991, Quebec announced that pulp and paper mills will be required to upgrade facilities by the end of 1996 to meet a new set of tougher pollution laws backed by hefty fines.⁶ The upgrading was expected to cost \$1 billion. As part of its plan to cut the 10 million tonnes of trash going to Ontario dumps each year by at least 25 per cent by 1992 and at least 50 per cent by the year 2000, Ontario proposed legislation requiring businesses, industries, and public institutions to separate their garbage for recycling beginning in the summer of 1992,⁷ and requiring companies that manufacture food, beverages, paper, and chemicals to make plans for reducing the amount of packaging they use or produce. These initiatives demonstrate the pervasiveness of the sustainability ethic, but the feasibility of implementing them has yet to be fully demonstrated. Such initiatives do, however, provide opportunities for novel applications of science and technology for new, more efficient processes and products that reduce waste at source, provide for easy recycling, and enhance reuse – the “three Rs” of sustainability.

Municipal governments have also been active. For example, in 1991 the city of Toronto released a Declaration on the Environment. This ambitious initiative sets fundamental objectives and guiding principles that serve as an overall framework within which the municipal corporation and individual departments can operate in a coherent fashion with respect to environmental concerns. The city urged all members of the community to adopt its principles.

The response of the private sector to the emergence of the sustainability ethic has been one of the more interesting aspects of the past year's events. For example, there seems to have been real movement in the thinking of business on public accountability, observable through annual statements of intention and report cards on progress. Noranda Forest produced its first environmental report in 1991. Dow Chemical Canada has produced annual environmental progress reports for the past three years. Corporate environmental reporting is a new approach to public account-

Box 1. Announcements of Green Plan Initiatives, 1991

In March - \$25 million to prevent toxin release into the Great Lakes and St. Lawrence basin - by developing strategies with industry and municipalities that spell out targets, schedules, and actions; by demonstration projects (as well as seed money for industry) to test new pollution prevention technologies; and by a public awareness campaign.

In June - \$100 million to clean up B.C.'s Fraser River - \$14 million for research on the persistence and impact of toxins placed in the river, \$15 million for partnerships (such as sustainable development demonstration projects), \$27.8 million for pollution cleanup, and \$57.2 million to restore the natural environment.

In June - \$100 million for a new marine environmental emergencies response strategy to deal with disasters like 1990's Exxon Valdez oil spill off the Pacific coast: \$36 million to be spent on prevention, \$60 million on preparedness, and \$4 million on new policy.

In August - \$25 million to help protect the ozone layer: \$9.2 million to hasten the elimination of ozone-depleting substances and \$15.8 million to boost Canada's ability to study and monitor the vulnerable arctic ozone layer.

In September - \$100 million to foster sustainable development of the country's forests. The program will create up to eight model forestry areas across Canada where a mix of commercial exploitation, recreation, and scientific studies will be conducted.

In September - \$50 million to create a series of environmental studies fellowships, research chairs, and ecosystem research grants within the nation's universities.

In October - \$100 million to help business develop pollution abatement technologies for domestic and international markets.

In November - \$25 million to establish an emergency team to respond to spills of hazardous chemicals and oil anywhere in Canada, and for spills research and the development of cleanup instruments and techniques.

In November - \$10 million to monitor and minimize the dumping of garbage into the ocean.

In November - \$25 million to reduce the garbage and hazardous waste produced by Canadians.

Source: Environment Canada news releases.

ability by industry and is in itself an accomplishment. Firms often use the reports to argue their positions on various controversial environmental issues, but they also highlight accomplishments and problem areas, and address energy efficiency gains, recycling efforts, and environmental R&D programs. The evidence indicates that at least some firms in Canada are placing increasing importance on the integration of environmental concerns within the usual processes of business

management, with an emphasis on the development of more environmentally benign processes and products.

Another indication of industry's response in the past year is its willingness to participate in serious consultation and consensus building with environmentalists on major environmental problems. An example is the work of the New Directions Group, which consists of top executives from several of Canada's industrial giants,

including Dow Chemical Canada, Noranda Inc., E.B. Eddy, Nova Corp., Dofasco, and Dominion Textiles, and environmental groups, including Pollution Probe, the Canadian Nature Federation, the Canadian Institute for Environmental Law and Policy, and the Canadian Arctic Resources Committee. In September 1991 this group delivered an action plan to the federal government to eliminate dumping of toxic chemicals.⁸ The plan calls for action on two fronts – to immediately establish a national inventory of pollution emissions as described in the Green Plan, and to initiate a process for targeted reductions, including the phasing out of some substances by the year 2000.⁹ This is a landmark action plan; it will be interesting to see whether consumers will be willing to pay the price for its aggressive and visionary measures.

In November 1991, Canadian packaging manufacturers announced they will spend more than \$1 billion to follow a voluntary code of preferred packaging practices that will reduce the amount of packaging going into landfills. The target is to cut the current amount of about nine million tonnes a year in half by the year 2000.¹⁰ The move could spell an end to such things as toothpaste boxes, plastic bubble or blister packages, and nonrefillable containers for everything from glue to oil.

It is far too early to assess the implications of public and private sector sustainable development initiatives announced over the course of the past year. So many are statements of purpose, new programs, or proposals for policies and targets, and few have had the benefit of full implementation. But opinions that have been voiced to date range from praise, albeit somewhat tempered, to condemnation.

For example, Ontario's proposed waste reduction legislation was welcomed by environmentalists, who praised the government for doing "pretty well" what it promised in mandatory source separation and recycling.¹¹ The Green Plan's \$100 million program to clean up British Columbia's Fraser River was seen by environmentalists as "very positive," provided it did not lead to yet more studies.¹² Still others expressed optimism owing to the steady pace of announcements on Green Plan spending decisions, but feared that the six-year federal environmental strategy is a grab-bag of unrelated programs with no overall objective.

On the other hand, sustainable development initiatives have been condemned, in particular by

industry and labour, because of their potential for business closures and job losses. For example, Ontario's proposed waste reduction legislation was seen as placing an onerous burden on thousands of small firms already struggling because of the recession.¹³ Quebec's new pulp and paper mill effluent standards were viewed by one industry spokesman as financially impossible: some plants would be forced to close.¹⁴ The federal government's new pulp mill effluent regulations also were criticized by the forest industry for being too expensive.

The capital cost of changing production processes or installing pollution controls will no doubt pose a challenge to the ability of Canada's forest industry to remain competitive in the global marketplace, but one must ask if the industry paid adequate attention to the changing tenor of public attitudes and expectations in those years of good returns on investment. In the rush to become more competitive, most forest companies are now slashing spending wherever possible, including severe cutbacks in their R&D operations.¹⁵ It would perhaps be timely to remember Michael Porter's contention that global competitiveness can be fostered by innovation that responds to stiffer environmental regulations.¹⁶ Canada has both the stimulus through tough regulations and the competence to be a leader in many environmentally benign technologies. International trade shows such as Globe '92 in Vancouver, and Investment Canada's aggressive promotion of foreign partnerships in such technologies as waste-water treatment and bioremediation, showcase Canadian strengths that should be further developed if we are to gain market leads over our competitors.

Corporate threats to close factories often succeed in mobilizing workers and communities to oppose firmer regulatory policies, and this often results in the delay of new regulations – a delay typically attributed to the need for more study. For example, Environment Canada announced in December 1991 that although it would go ahead with regulating dioxins and furans in pulp mill effluent, two more years of study would be needed before it could decide whether to regulate all remaining chlorinated organic compounds – a family of more than 1000 compounds in waste water from pulp mills – even though they were originally scheduled to be strictly controlled under the new pulp mill regulations.¹⁷ Is this a case of a premature policy action that was not preceded by adequate consultation and

investigation of feasibility, or a case of delaying the inevitable?

While there are undoubtedly examples of new environmental laws throwing workers out of their jobs and decimating the economic base of a community, the question may be as much one of when, not whether, such industries will be forced to change or go out of business. As noted by a recent Worldwatch Paper,

Polluting industries are at best a marginal – and now shrinking – source of jobs. . . Even in the absence of environmental policies, many of these jobs are disappearing.¹⁸

Surely Canada must seize the opportunities inherent in public attitudes towards sustainability, not just live with the consequences.

Or Is It Just Business as Usual?

At the same time as many decisions consistent with sustainability are being made, other decisions on policy, priorities, and spending directed at the development and use of science and technology are being made that contradict sustainable development principles.

In a report card released to coincide with the opening of the 1991 summit of the seven major industrialized nations, a consortium of environmental groups gave Canada poor marks on almost all aspects of environmental protection, save public relations:

Canada's marks on a wide array of relevant environmental topics, ranging from international relations to actual pollution control measures reflect very little action – so far. In particular, performance on the key problems of water pollution, waste management, agriculture, global warming, and transportation dragged scores way down. Even relatively good marks in global relations were marred by very low grades in trade relations.¹⁹

The OECD's *State of the Environment* report for 1990 gives Canada some of the worst marks among the 24-member group of industrial nations in many of its 18 environmental indicators.²⁰ For example, Canada was ranked fourth worst out of 21 OECD countries in per capita production of municipal waste; third worst out of 21 in growth of the use of nitrogenous fertilizers on arable land; the worst for per capita sulphur oxide emissions; second worst for per capita nitrous oxide emis-

sions; worst for production of nuclear waste per total primary energy requirements; and worst for per capita energy consumption.

In its *Environmental Assessment of the Federal Budget*, Resource Futures International analysed the 1991 budget and spending estimates in energy, agriculture, and regional and industrial development to determine their environmental impact. It reported that the government planned to spend \$731.6 million in 1991-92 on programs to support industries that supply fossil fuels and nuclear power, but just \$34.7 million encouraging energy efficiency.²¹ Similarly, it noted that the huge costs of cleaning up pollution caused by burning fossil fuels are not taken into account when the government subsidizes oil and gas megaprojects such as the Hibernia field off the coast of Newfoundland. And more than 80 per cent of agricultural funding was seen as going to environmentally destructive programs, with less than 20 per cent going to controlling soil erosion and other sustainable agricultural initiatives.

But by selectively describing isolated indicators, these reports can be misleading. What are most relevant are those reports that place the micro-indicators (e.g., the growth in the use of nitrogenous fertilizers) in the context of the broader ecosystem being examined (e.g., the overall nutrient balance and soil quality) and that in turn examine both the economic and the environmental side of the balance sheet. There is rarely an inherent rightness or wrongness to the use of a "tool" such as a fertilizer or a pesticide. It is the overall outcome relative to the goal of environmental and economic sustainability that must be the operational focus.

In its report card released in September 1991, the World Wildlife Fund gave universally low marks to the federal, provincial, and territorial governments for protecting wilderness in Canada. The report says that Canada lags behind many other countries, including the United States, Australia, and Costa Rica, in saving wild areas. It notes that even though in the Green Plan the federal government adopted the goal of preserving at least 12 per cent of Canada's lands and waters as wilderness and pledged to complete the national parks system by the year 2000, no progress had been made toward the goal in the past year. Only 3.4 per cent of Canada was protected as wilderness, the same amount as the year before. Instead, the report notes, in 1990-91 Canadian governments promoted some of the

largest developments in the world, including hydroelectric dams in Quebec, pulp mills in Alberta, and a copper mine in British Columbia.²²

Similar conclusions were reached in a report also released in September 1991 by the Canadian Environmental Advisory Council. The report says that Canada's national parks are under threat. It notes that logging, acid rain, pulp mill pollution, and underfunding are contributing to the degradation of the parks system.²³

In a report released in February 1991, a U.S. and a Canadian environmental group noted that "levels of problem toxics in the Great Lakes are no longer declining, and some measurements indicate that the most hazardous forms of some chemicals are actually increasing."²⁴ Meanwhile, a report on the Great Lakes from the International Joint Commission warned that "there is a threat to the health of our children emanating from our exposure to persistent toxic substances, even at very low ambient levels."²⁵

In studies released in February 1991, both the industry and the Ontario government reported that 20 of Ontario's 27 pulp and paper mills are discharging effluents, including dioxins and furans, in their waste water that are toxic enough to harm wildlife.²⁶ Environmentalists in Europe and Canada have been urging Europeans not to buy Canadian forest products until they are free of chlorine and chlorine dioxide. Chlorine, used in the paper bleaching process in Canadian pulp and paper mills, produces many by-products including dioxins, furans, and other organochlorines. Particular product targets include disposable diapers in Britain and chlorine-bleached paper in Germany.

The movement for chlorine-free pulp and paper got a boost in Germany in March 1991 when Greenpeace published *Das Plastik*, a takeoff on *Der Spiegel*, the country's giant weekly news-magazine. It was printed on paper made entirely from chlorine-free pulp supplied by a Swedish mill, and included highly critical articles about British Columbia's pulp industry practice of dumping dioxins and furans into the Thompson River. The environmentalists' campaign has already had an impact on Canadian pulp producers. Some German buyers of B.C. pulp have stopped purchasing products that are bleached with some types of chlorine. As a result, some British Columbia companies have lost sales.²⁷ However, recent news reports of a trial chlorine-free process being instituted by Howe Sound Pulp and Paper Ltd. in British Columbia are

indicative of industrial will to respond to the new societal values using science and technology as part of the solution.²⁸

The Canadian forest industry also faces the threat of a European boycott of its forest products over the clearcutting of old-growth forests, particularly those on the British Columbia coast. Talk of a European boycott of Canadian forest products began surfacing in June 1990. Fears of a boycott grew after an illustrated article appeared in the September 1990 issue of *National Geographic* describing British Columbia's logging practices as among the world's worst; the airing in March 1991 on German prime-time television of a documentary, "A Paradise Despoiled," calling British Columbia the "Brazil of the North" in reference to that country's environmental record with its rainforests; a highly critical piece on British Columbia's logging practices was published in the May-June 1991 issue of *Sierra*, the magazine of the U.S.-based Sierra Club; and a two-page spread appeared in the July 1991 issue of *Time* magazine talking of the destruction of British Columbia's temperate rainforests. Is the problem as serious as the media contend? Whatever the truth, public attitude is being polarized. One side sees the public as being manipulated by the unscrupulous media; the other sees the industrial forest giants as a machiavellian force. Issues are rarely as "clear cut." Recent discussions between representatives of the Canadian forest industry and the European Community have reinforced what many suspected - that we have been exposed to two sets of extremist views of a serious situation. But it is a situation that is being tackled by our forest industry, if more slowly than society demands. At year end 1991, representatives of the EC were not demanding a boycott.

Policy and project environmental assessments have fuelled the most heated environmental criticisms of the past 12 months. Whereas once environmental assessment was simply a way to react to concerns about certain large projects, it is now expected to be a proactive process that addresses the multifaceted and long-term issues that surround the notion of sustainable development. It also opens up the very touchy issue of federal versus provincial jurisdiction. Public wrangling over jurisdiction undermines the federal government's credibility with the Canadian public over its plans to finally pass new environmental assessment legislation aimed at ensuring all major resource and industrial projects are reviewed.

Because it was not specifically mentioned in the 1867 Constitution, jurisdiction over the environment, now shared by federal and provincial governments, has a history of being disputed. In its September 1991 constitutional proposals, the federal government proposed that the environment be mentioned in the Constitution in a "Canada Clause" in the preamble, which would describe who Canadians are and what they believe in. But the government did not propose to incorporate reference to the environment in other sections.²⁹ Environmental lawyers contend that by not defining who has jurisdiction over the environment, the federal government has missed a chance to make murky waters much clearer.³⁰ Some provinces are concerned that their rights to local development and self-determination are being jeopardized.

There is also concern that many federal policy decisions are made before their environmental implications are assessed. According to Liberal MP Charles Caccia:

Successive energy budgets are making us increasingly dependent on non-renewable sources while virtually ignoring renewable forms of energy.... In the case of cuts to Via Rail, the environmental implications actually emerged as an afterthought.... More recently, we have been told by the minister of the environment that the proposed North American free trade agreement with Mexico and the United States will be examined for its environmental impact after the agreement is negotiated.³¹

Moreover, it is argued that, to date, the federal government's current dialogue on national prosperity, intended to drive future economic policy decisions, lacks an in-depth understanding of the links between sustainable development and competitiveness. Comparable questions have been raised by the Michael Porter study on competitiveness.³² In the 1991 annual report of the National Round Table on the Environment and the Economy, the chairman notes:

There has been little public focus on the relevance of sustainable development to the debate. This may be due to the prevailing belief that sustainable development is an impediment to competitiveness or a luxury Canada can afford only when we have a more secure competitive position in export markets.³³

The chairman of the National Round Table rejects that belief. Instead, he says:

Canada can aspire to leadership in the technology and design of new products and services for which demand will grow as the world economy recognizes and adapts to the importance of sustainability.³⁴

The federal government recently commissioned the National Round Table on the Environment and the Economy together with the Institute for Research on Public Policy to conduct a detailed study to examine the linkages, convergences, and divergences between competitiveness and sustainability, and the manner in which strategies might be harmonized to achieve sustainable economic development in a global environment.³⁵

The pattern of making important policy and project decisions before assessing the implications for the environment has generated public ire at other levels of government. For example, in early 1991 the Quebec government indicated it intended to go ahead with the construction of needed roads, airports, and other infrastructure for the \$12.6 billion Great Whale hydroelectric project in northern Quebec without waiting for federal environmental assessment. In August, the Quebec government delayed the start of the project for a year, and in October it announced that it would conduct an all-inclusive environmental impact study of the development. But this was only after the international press had focused on the issue, causing Quebec major international embarrassment. Proceeding with large resource and industrial development projects without environmental assessments is no longer accepted by Canadians. Public attitudes have changed even more rapidly than political decision-making systems. It is not clear, however, whether the public is fully aware of the implications of its concerns in terms of increased taxes or cuts in public services.

Climate change is widely considered to be the environmental problem that potentially has the most far-reaching long-term consequences for the planet. In fact, the issue of climate change is expected to be one of the central focuses of the Earth Summit in June. Canadian leadership in the organization of the summit is evident. A Canadian, Maurice Strong, is Secretary General of the conference and several federal government officials are playing a catalytic role in developing

elements of the agenda. Although the outcome of the conference is by no means certain, the vision and international stance of the Canadians involved has yet to be matched on the domestic front. The federal government is already committed to capping carbon dioxide emissions – the main culprit in the gradual warming of the earth – at 1990 levels by the year 2000, but has been criticized for not producing an action plan on how this is to be achieved. If current trends continue, emissions will rise substantially. A National Energy Board 20-year forecast shows that our growing use of oil, natural gas, and coal will continue to accelerate carbon dioxide emissions. Canada produced 533 million tonnes of carbon dioxide in 1989; the NEB says by 2010 we will be adding 675 million tonnes a year to the earth's atmosphere.³⁶

In a unanimous report released in March 1991, the House of Commons Standing Committee on Environment noted that although Canada's per capita contribution to greenhouse gas emissions is higher than that of any other major country, "the national action that has been taken so far is widely perceived to be tentative and inadequate."³⁷ The committee described programs to improve energy efficiency and promote cleaner alternatives as "half-hearted and intermittent."³⁸ Federal spending on energy efficiency between 1984 and 1988 fell by 80 per cent,³⁹ and major fossil fuel developments continued to receive billion-dollar subsidies. The federal government is under pressure from environmental groups to commit to a 20 per cent reduction in carbon dioxide emissions by the year 2005 prior to the Earth Summit in June. Meantime, the oil industry has been sounding alarm bells that restraining the burning of fossil fuels to curb carbon dioxide emissions will hurt the economy. A recent Imperial Oil study said stabilizing emissions by imposing a heavy tax on them would slash Canada's gross domestic product by \$100 billion over 15 years.⁴⁰ What action should be taken, what are the costs and benefits of various options, and how quickly should Canada proceed? These are difficult questions, and to answer them all facets of the balance sheet will have to be considered.

Positive Signs, But a Long Way to Go

Inevitably the question is this: Do we have reason to be optimistic about the possible contributions of science and technology in solving our environ-

mental problems and maintaining a clean and healthy environment? And will our public policy measures be up to the challenge?

Although solutions to many ecological problems seem dishearteningly far away, improvements are being made. For example, the Canadian Coalition on Acid Rain recently declared a victory and plans to wind down after a decade of fighting acid precipitation. It feels that its efforts to protect the nation's trees and lakes are paying off, and that it has achieved its main goal. The quantity of sulphur dioxide emanating from smelters, industrial smokestacks, and coal power plants fell 12.5 per cent in eastern North America from 1980 to 1987. According to the 1990 report of a federal-provincial government research and monitoring committee, these drops have begun to cut the acid levels in rain and snow by as much as 30 per cent in some areas of eastern Canada. The decline in acid precipitation will be even more dramatic after 1995, when the effect of rulings in Canada and the United States calling for sulphur dioxide emissions to be cut by 50 per cent by 1994 from their 1980 base will have begun to show.⁴¹

It is equally obvious that there is still a long way to go. Public and private sector policies, priorities, and spending directed at the development and use of science and technology are still having little impact in alleviating environmental degradation. Industry, government, and the public are increasingly acknowledging that great changes lie ahead. Fundamental changes in the way products are produced, consumed, and disposed of are unavoidable, and the scientific and technological opportunities are far from exhausted.

The challenge is to take action today. We must develop goals and action plans even though there are gaps in our knowledge and inadequacies in our ability to monitor and assess environmental impacts. The costs of inaction are too high to accept extended delays. We must move ahead now with both action plans and a forward-looking research agenda. This research agenda must tackle the need for an improved portfolio of environmental indicators and probe the gaps in our knowledge of the links between human and natural effects in ecosystems. We must train people capable of dealing with complex, multidimensional scientific problems and responsibly communicate scientific knowledge to the public. We must reassess the balance between such things as green spaces and urban areas, between the scientific and technological and the societal and cultural sides of the equation. But most of all,

we must develop a visionary approach to sustainable development, an approach that all Canadians can support and to which the science and technology community can contribute.

Notes

1. This debate has considerable historical conditioning, part of which can be traced back to the late 1960s and 1970s, including the green movement, the work of the Club of Rome on limits to growth, and the Science Council's work on the conservator society. See Science Council of Canada, *Canada as a Conservator Society: Resource Uncertainties and the Need for New Technologies*, Report 27 (Ottawa: Minister of Supply and Services Canada, 1977).
2. World Commission on Environment and Development, *Our Common Future* (New York: Oxford University Press, 1987).
3. Government of Canada, *Canada's Green Plan* (Ottawa: Minister of Supply and Services, 1990).
4. Environment Canada, "New Federal Regulations to Control Pulp Mill Pollution," news release, Ottawa, 4 December 1991.
5. Fisheries and Oceans Canada, "Northern Cod Science Program," news release, St. John's, 5 December 1990.
6. Cabinet du ministre de l'Environnement, Gouvernement du Québec, "Le Ministre Paradis annonce un nouveau règlement," news release, Québec, 4 September 1991.
7. Ontario Ministry of the Environment, Waste Reduction Office, *Initiatives Paper Number 1*, Toronto, 1991, 1.
8. New Directions Group, "Industrialists and Environmentalists Introduce Plan to Reduce and Eliminate Emissions of Toxic Substances," news release, 26 September 1991, Appendix 3.
9. *Ibid.*, 2.
10. Packaging Association of Canada, "Packaging Industry Supports Code of Preferred Packaging Practices," news release, Halifax, 6 November 1991.
11. Pollution Probe researcher Ellen Schwartzel interviewed in Peter Gorrie, "Institutions, businesses told to begin recycling trash," *The Toronto Star*, 10 October 1991, A2.
12. Barry Leach of the Fraser Wetlands Habitat Committee interviewed in "Big Budget Effort to Clean up Fraser River," *Probe Post* 14(2) (Summer 1991): 40.
13. Canadian Federation of Independent Business spokesperson interviewed in "Institutions, businesses told to begin recycling trash," *The Toronto Star*, 10 October 1991, A2.
14. André Duchesne, president, Quebec Association of Forest Industries, in "Quebec's standards too tough, official says," *The Ottawa Citizen*, 25 October 1991, B7.
15. Science Council of Canada, forthcoming report on the Canadian forest products sector, sectoral technology strategy series.
16. Michael E. Porter, "America's Green Strategy," *Scientific American* (April 1991): 168.
17. Environment Canada, "New Federal Regulations to Control Pulp Mill Pollution," news release, Ottawa, 4 December 1991.
18. Michael Renner, *Jobs in a Sustainable Economy*, *Worldwatch Paper* 104, September 1991, 11.
19. Friends of the Earth, Pollution Probe, World Wildlife Fund, *The Summit: Environmental Accountability Project*, 15 July 1991, 2.
20. Organisation for Economic Co-operation and Development, *The State of the Environment* (Paris, 1991).
21. Resource Futures International, *Environmental Assessment of the Federal Budget* (Ottawa, March 1991), 10-11.
22. World Wildlife Fund Canada, *Endangered Species Progress Report*, no. 2 (Toronto, 1991).
23. Canadian Environmental Advisory Council, *A Protected Areas Vision for Canada* (Ottawa: Minister of Supply and Services, 1991).
24. National Wildlife Federation and Canadian Institute for Environmental Law and Policy, *A Prescription for Healthy Great Lakes* (February 1991).
25. International Joint Commission, *Persistent Toxic Substances: Virtually Eliminating Inputs to the Great Lakes*, interim report prepared by the Virtual Elimination Task Force of the International Joint Commission (Ottawa, July 1991), 7.
26. "Pulp industry says 20 mills emitting toxins," *The Ottawa Citizen*, 6 February 1991, D12.
27. Patricia Lush, "Europeans join B.C. logging fight," *The Globe and Mail*, 10 June 1991, B2.
28. "Green pulp trial at European mill draws B.C. eyes," *The Globe and Mail*, 27 January 1992.
29. Government of Canada, *Shaping Canada's Future Together: Proposals* (Ottawa: Minister of Supply and Services, 1991).
30. Anne McLroy, "No harm: Clark says plan won't hurt environment," *The Ottawa Citizen*, 26 September 1991, A2.
31. Charles Caccia, "Implementing Sustainable Development," *Policy Options* (November 1991): 27-28.
32. Michael E. Porter and the Monitor Company, *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Business Council on National Issues and Minister of Supply and Services, October 1991).
33. National Round Table on the Environment and the Economy, *A Report to Canadians* (Ottawa, June 1991), 1.
34. *Ibid.*, 2.
35. National Round Table on the Environment and the Economy, "National Round Table and Institute for Research on Public Policy Launch Major Initiative on Sustainability and Prosperity," *National Round Table Review* (Fall 1991): 1-2.
36. National Energy Board, *Canadian Energy: Supply and Demand 1990-2010* (Ottawa: Minister of Supply and Services, June 1991).
37. House of Commons Standing Committee on Environment, *Out of Balance: The Risks of Irreversible Climate Change* (Ottawa: Minister of Supply and Services, March 1991), 39.

38. Ibid., 29.
39. This decline includes spending on conservation, R&D, information, alternative transportation fuels, and incentives (grants) to increase energy conservation. Total spending on energy efficiency by the Department of Energy, Mines and Resources fell from \$482.9 million in 1984-85 to \$93.4 million in 1988-89. Of this decline, \$339.9 million is accounted for by the cessation of the incentives program (Nick Mardy, Energy, Mines and Resources, personal communication, 4 February 1992).
40. Imperial Oil Limited, *A Discussion Paper on Global Warming Response Options* (Toronto, April 1991), 25.
41. Martin Mittelstaedt, "Canadian activists signal victory in fight against acid rain," *The Globe and Mail*, 19 February 1991, A1.

5. New Frontiers

Everywhere these are exciting times on the frontiers of science and technology, but they have produced a certain discontinuity. On the one hand, governments increasingly see advances in science, engineering, and medicine as powerful instruments for social change and comparative advantage in a hotly competitive global economy. On the other hand, scientific, medical, and technological enterprises are beset by organizational, institutional, and professional challenges arising largely from public expectations – expectations fuelled by the pace of discovery and by the impact of innovation. Indeed, public pressures on the institutions supporting the pursuit of scientific knowledge and technological advance have come to have just as much if not more weight than the agendas traditionally set by the research community itself.

It is largely a question of accountability, and the debate – a very healthy debate – is hardly unique to Canada; it is under way in all the industrial nations. In the United States, the president of the American Social Science Research Council, Kenneth Prewitt, has summarized the situation as follows:

As science and technology have pervaded the public agenda, then the deeply held political values of democratic accountability and public scrutiny have naturally and inevitably impinged on science policy. Demands for observable benefits from public investment in science increase. And there are expectations that science should be subjected to the same principles of regulation and accountability as govern other important sectors of public life.... It is too late for science to evade the consequences of the participatory democratic culture in which it is practised and from which it draws support.¹

In the following pages we sample some of the activity on the new frontiers of science and technology and trace the developments in Canada's thinking about emerging science and strategic technology. To illustrate some of the issues, we focus on events in biotechnology and space. In addition, we examine the "big science, little science" problem (a dilemma for every small country like Canada), with particular reference to the controversial KAON project.

International Trends

The push for accountability and the contest between "megascience" and "modest science" are only two of several signs that the research community is under considerable pressure. Others include (in no particular order): the increasing complexity and cost of forefront research instrumentation, techniques, and facilities; the inability or unwillingness of the scientific and technical communities to set their own priorities within the context of the current public policy environment; the emergence of the concepts of "strategic" research and "strategic" (or "critical" or "emerging" or "generic") technologies and their implications for the management of technology; the transformation of knowledge for the "public good" from a cultural investment to a commodity; the rise of multinational partnerships and the development of research networks; and the clamour for increased public scrutiny of the impacts of frontier science.

In the Western industrial economies these debates are conditioned by each country's political, economic, and research systems and the ways that science, technology, engineering, and medicine are practised. In the United States the debate is about priority-setting mechanisms in science, the need for a critical technology strategy as a result of the perceived erosion of the country's technological leadership, scientific integrity, overhead costs for research, and the ability to meet expectations as a reliable international partner in S&T (particularly in big science).²

Japan, while defending its system against charges of technological protectionism, is under pressure to contribute more to the world pool of basic scientific knowledge.³ Germany is trying to absorb the S&T capacity of the old German Democratic Republic while simultaneously adjusting to the pressures of a single European market. Switzerland, historically one of the largest spenders in R&D (at least on the basis of gross national product), is concerned about the increasing tendency of domestic multinationals to move their research operations overseas; as a consequence, the Swiss have introduced new measures to strengthen the home base for science and technology. Britain is preoccupied with a funding crisis in basic research, the "brain drain," and

issues related to dual-use technologies (i.e., the conversion of defence R&D systems to civilian applications).

Meanwhile, the frontiers of knowledge continue to advance. A distinguishing feature of much frontier activity is intense interdisciplinarity. Success requires close cooperation among an increasing number of specialists. For instance, the Japanese Agency of Industrial Science and Technology is sponsoring a 10-year project to conduct fundamental research on micron-scale machines (which can have applications as diverse as non-invasive diagnostic tools in medicine, or devices designed to carry out inspection and repair in restricted spaces, such as aircraft engines).⁴

Over the past year, one of the most exciting chemical discoveries emerged from a joint American-German scientific team which found a simple method for producing carbon 60. Named buckminsterfullerene (after the American architect), but known as the "buckyball" because of its soccerball-like structure, the molecule is already being touted as having significant potential for application in lubricants, batteries, drugs, magnets, and superconductors. The American journal *Science* has designated this 1991 discovery as "Molecule of the Year."

In fusion energy research, work is under way to develop the next generation of experiments for a proposed International Thermonuclear Experimental Reactor by building on the work of such facilities as the Joint European Torus in the United Kingdom and the Tokamak facility in Varennes, Quebec. In 1991 the European facility succeeded in demonstrating the technical feasibility of nuclear fusion. And the list of advances goes on.

The Canadian Scene

The frontiers debate in this country has necessarily been coloured by the constitutional challenge, recovery from recession, and the struggle for competitiveness.⁵ These issues have proven inescapable in the effort over the past year to identify and enhance, for example, niche capabilities in health care, biotechnology, new materials, remote sensing, and advanced manufacturing technology. Expectations in these areas, in turn, place added pressure on the underlying research base to help provide ideas, linkages to international networks, and skilled personnel. One way or another, competitiveness and constitutional matters also impinge on the question of invest-

ments in large-scale science such as those associated with high-energy physics, astronomy, and global climate change.

In addition, because the emerging pattern of research and innovation is intensely interdisciplinary, there is increased experimentation with new institutional forms for organizing and disseminating research (e.g., the Canadian Institute for Advanced Research, PRECARN Associates Inc., the Fields Institute for Research in Mathematics, the Institute for Chemical Science and Technology, and the Networks of Centres of Excellence).⁶

The private sector has made some effort toward gaining a capacity to absorb breakthrough and best-practice technology in product or process lines. A number of companies are beginning to appreciate the strategic value of developing core competencies within their firms, as discussed in Part 2 of this report, "Competing through Innovation."

Technology-driven megaprojects aimed at strengthening and upgrading economic capacity have received considerable attention. These include the national high-speed communications network, the feasibility study for a Québec-Windsor high-speed train, and the Hibernia drilling platform, to name a few.

Over the past year, there has been considerable analysis of the innovative capabilities of Canadian firms as well as the difficulties of adjusting to new, rapidly moving, science-based technologies. Several firms, particularly in telecommunications (e.g., Teleglobe Canada, Northern Telecom) and pharmaceuticals (e.g., IAF Biochem, Quadra Logic Technologies), have taken up this challenge. In the more traditional resource-based industries, some effort is also under way to integrate new technologies in order to diversify existing product lines (e.g., the work of Sheritt Gordon in advanced materials, and of MacMillan Bloedel in new materials for wood products). Reports by the Science Council of Canada, Kodak, the Canadian Institute for Advanced Research, the National Advisory Board on Science and Technology, and the Monitor Company (Michael Porter) have all argued for a better appreciation of how innovation takes place at both the corporate and national levels, and have provided some focused input to the debate.⁷

Industrial research and trade associations such as the Canadian Advanced Technology Association, the Society of the Plastics Industry of Canada, the Canadian Advanced Industrial Materials Forum, and the Pulp and Paper

Research Institute of Canada have been active in promoting new organizations that bridge the gap between advanced technology and commercial production.

With respect to technology transfer and diffusion – a critical element of the country's ability to capture and test technological advances both at home and abroad and translate them for local markets – several initiatives and organizations have been established or strengthened (e.g., the Canadian Industrial Innovation Centre in Waterloo, the Institut des biomatériaux in Québec, the B.C. Advanced Systems Institute in Vancouver, and the Canadian Institute of Fisheries Technology in Halifax). Further, a number of provincial governments, including Ontario, Quebec, Alberta, and British Columbia, are engaged in identifying their strategic strengths in technology and science as well as the requisite diffusion systems.⁸

In the sciences, particularly the so-called "little" sciences, there have been some important developments. Although it is difficult to canvass the overall shape of Canadian activity at the frontiers of science, mathematics, medicine, and engineering, the Natural Sciences and Engineering Research Council has taken the innovative approach of asking the academic research community, through NSERC's disciplinary grant selection committees, to develop statements on the "Health of the Disciplines." These reports are designed to identify future issues facing the research community as well as the extent to which it is prepared to tackle them. Specifically, the reports are intended to outline:

- the current strengths and weaknesses of the discipline in Canada;
- emerging trends over the next 5-10 years;
- those international programs in which Canadian participation is anticipated or desirable;
- changes in research funding needs;
- predictions for graduate student enrolments in the discipline;
- other aspects of research and funding that relate to maintaining excellence and international competitiveness.

These state-of-the-discipline reports will be helpful in planning the Canadian presence in future international scientific endeavours as well as assisting decision makers in forecasting trends. Wider circulation of these statements to the

science and technology communities would greatly assist the national debate on the country's science agenda.

Developing Strategic Assets

Strategic or enabling technologies have become the currency of innovation. Because of their ability to underpin a multitude of new products and services, as well as their potential to advance productivity and quality, these technologies are universally promoted by industrialized nations.⁹

The United States has produced a series of policy reports on strategic technologies,¹⁰ as have Japan, Germany, Britain, and the Netherlands.¹¹ In most instances, the degree of detail and analysis is considerable, certainly greater than in any similar exercise Canada has undertaken. Indeed, Canada would do well to enhance its own long-term vision in this area.

While most national and subnational governments recognize the importance of biotechnology, informatics, space, advanced industrial materials, and advanced manufacturing techniques, and the private sector aggressively creates, adopts, and adapts these new technologies, the essential questions are: *strategic for whom, and to what?* The Canadian government, for example, in its Strategic Technologies Program, defines the term simply as "vital to sustained economic growth in Canada." This program, created in 1989 with a fund of \$90 million, has supported partnerships in strategic technology development dealing with informatics, biotechnology, and advanced materials.

The National Research Council of Canada, within the context of its long-range planning, has identified a set of strategic technologies that it sees as fundamental to its mandate (biotechnology, environmental science and technology, marine sciences and engineering, transportation technology, construction technology, industrial materials, automated manufacturing, and microelectronics).¹²

The question of critical or strategic technologies can be dealt with only in the context of national needs and industrial capacities. After all, as one observer has remarked, every business day sees approximately 5000 new research papers published and 1000 new patent documents issued.¹³

For instance, many commentators would not normally include cold-regions research on their

list of strategic areas, yet in the case of Canada and its circumpolar neighbours, developments in these technologies are critical to domestic economic development and international competitiveness. R&D in the areas of offshore oil and gas, steel structures in extreme environments, oceanographic research in cold seas, remote sensing in northern waters, environmental assessment sciences, and so forth, are some examples of Canada's niche capabilities in this "strategic" domain.¹⁴

The creation in February 1991 of the Canadian Polar Commission is testimony to the importance of polar activities in Canada.¹⁵ Among its responsibilities is the fostering of international and domestic cooperation in circumpolar research. Canada was actively involved over the course of 1991 in developing the program for the International Arctic Science Committee (Canada was the host for the founding meeting in 1990) and in working with other circumpolar nations on protocols for the protection of the arctic environment.

Canadian expertise in polar technology will play a key role in developing new export markets. For example, Canadian Marine Transport Group Ltd., a consortium of six Canadian firms, is developing technology-based trade links with Russia and other members of the Commonwealth of Independent States. A similar consortium, the Atlantic Canada Environmental Trade Association, has been established in the Maritimes to tackle environmental matters. In January 1992, Montréal was the site of a major international trade exhibition of polar expertise (Polartech '92), which served as a showcase for Canadian capability in this area.

Building on Strengths

Whether a technology is strategic to an industry or to a nation, certain mechanisms must be in place to be able to assess, adapt, and exploit the new knowledge. In short, an industry or a nation must have means by which new technologies can be chosen for adaptability to the local environment. This not only involves providing the necessary human resources to anticipate and manage new initiatives (about which more is said elsewhere in this report), but also entails completing the necessary organizational and workplace innovation to ensure the transition.¹⁶ As *New Scientist* makes plain,

a whole variety of people are involved in the interactions between science and technology. Product planners, designers, marketing experts, consumers, regulators, forecasters, and pressure groups all intervene, influencing what innovation theorists call the "selection environment" which produces particular technologies from a spectrum of possibilities.¹⁷

In 1985, the Science Council of Canada, with support from the Ministry of State for Science and Technology (now Industry, Science and Technology Canada), undertook a nationwide consultation on emerging technologies. The Canadian strengths identified then – areas in which Canada was seen as a world leader – were telecommunications, enhanced oil recovery techniques, synthetic fuels, remote sensing, computer software, and hydrogen technologies.¹⁸ Other areas of strength included advanced alloys, composite materials, conducting materials, biomass technologies, mineral leaching, coal technologies, ice engineering, and construction technologies. Seven years later, it is difficult to assess how much ground Canada has lost to, or gained on, international competitors in these fields.

A distinctive infrastructure has been created to provide homes for much of this research. In addition to regular university departments, multidisciplinary expertise has been consolidated in such institutions as the Alberta Oil Sands Technology and Research Authority (enhanced oil recovery), the Centre for Cold Ocean Resources Engineering and the Centre for Frontier Engineering Research (ice engineering), the Centre québécois pour la valorisation de la biomasse (biomass technologies), the High-Performance Concrete Network of Centres of Excellence (materials and construction), and the Telecommunications Research Institute of Ontario.

Canada has world-renowned expertise in the health and biomedical sciences. The country's medical schools are particularly well known. It is not surprising, therefore, to find that 6 of the 15 federally supported (and internationally peer-reviewed) Networks of Centres of Excellence are building on biomedical strengths. Among these centres are those associated with research in neural regeneration and functional recovery, bacterial diseases, genetic basis of human diseases, respiratory health, protein engineering, and promoting independence and productivity in an aging society.

In the geosciences, Canadian scientists are leading in a range of frontier research areas. Lithoprobe, a \$6.3 million project involving 28 universities, 17 industrial collaborators, and 13 federal and provincial agencies, aims to catalogue, characterize, explore, and map Canada's lithosphere, working to a depth of 100 kilometres. The multidisciplinary project has pioneered methods of scanning rock formations at great depths, allowing determination of their time and sequence of origin. New insights are helping to define areas of volcanic and earthquake activity, and to provide a framework for understanding where and why minerals, oil, and gas have accumulated.

In pharmaceuticals, the 11-member National Advisory Council on Pharmaceutical Research was appointed in 1991 to provide guidance on a range of issues. It will investigate how industry is capitalizing on the Networks of Centres of Excellence and examine other areas such as patent protection. There are lingering concerns that Canada's patent laws for pharmaceutical discoveries have not been competitive with those of other industrialized nations, and measures will be introduced to address these concerns.

Although these and other initiatives deserve applause, the longer-term view must recognize the need for adequate financing to *maintain* their operation (assuming the projects are viable and effective over the longer term). How governments, in particular, foster the creation and maintenance of R&D activity is an issue that merits close attention.

Alberta's Toward 2000 Initiative puts the matter in a strong economic light:

Strategic or enabling technologies – such as information and communications technologies, advanced industrial materials and biotechnology – are providing the basis for a fundamental transformation and restructuring of industry worldwide.... The linking of new, advanced and knowledge intensive technologies with our traditional resource and manufacturing industries is seen as a major advantage [Alberta] has over many foreign competitors.¹⁹

Biotechnology Means Business

To illustrate more concretely the issues associated with new frontiers and strategic technologies, we focus on the case of biotechnology. Biotechnology is a broad term: used to describe the production of innovative products, devices, and organisms

through the use of biological processes. It is not an industry. It is, as a U.S. report notes, "a set of biological techniques, developed through decades of basic research, that are now being applied to research and product development in several existing industrial sectors."²⁰ It is an enabling technology in the sense that it has the capacity to affect a wide variety of processes and organisms and to bring about advances in a wide range of applications.

Biotechnology has a huge economic potential. Forecasts of the size of the worldwide market for biotechnology-derived products range from \$9 billion to \$64 billion by the year 2000. Some have argued that "the second technological revolution will belong to those with the courage to create viable biogenetic products for the global market."²¹ Virtually all Western countries have some form of biotechnology strategy to ensure appropriate steps are taken to develop a strong biotechnology sector.²² Canada is no exception.

The National Biotechnology Strategy (NBS), in place since 1983, has gradually moved from providing support for some of the scientific research that underpins the technology (in government labs and universities) to fostering a supportive environment for commercialization and technology transfer (through patent issues and regulatory frameworks). It should be noted that much of the basic research that underlies biotechnology was conducted in the 1970s and early 1980s in Canadian universities (funded by NSERC) and in other research facilities, notably the National Research Council. It is still being developed today, some of it funded by the NBS. But the role of the NBS has evolved because of advice and pressure from the users and producers of biotechnological techniques and from the National Biotechnology Advisory Committee (NBAC).²³

The NBAC, which advises the federal Minister for Science, has been instrumental in promoting an internationally competitive Canadian position in biotechnology. In its recent policy work, the NBAC has tackled the development of a national business strategy for biotechnology and has dealt with waste management, agribusiness and food, intellectual property, and regulatory affairs.

Comprising some 18 experts from the business, financial, and academic communities, the NBAC is not the only major advisory structure on biotechnology. A number of provincial governments have advisory boards that have also been active in setting guidelines for the development of a strong biotechnology research and industrial

Box 1. Canada's National Biotechnology Strategy

The goals of the National Biotechnology Strategy are to: maintain a strong research base for the development of biotechnology; increase the supply of highly qualified personnel; enhance scientific cooperation and technology transfer between government and university laboratories and industry; and foster an economic and regulatory climate that is conducive to the commercialization of biotechnology.

The major elements of the strategy are:

- the National Biotechnology Advisory Committee, which provides independent advice to the Minister for Science, from the private sector and academia, on the progress of the biotechnology strategy and identifies specific issues and policy needs to support the development of biotechnology.
- the Interdepartmental Committee on Biotechnology, which coordinates the activities of federal departments and agencies involved in biotechnology R&D.
- the National Biotechnology Networks, which facilitate communication and cooperation among those involved in biotechnology R&D across Canada.

The networks include:

Aquatech	(fisheries/marine aquaculture)
Biozotech	(animal development)
Biocrop	(plant strain development)
Biorem	(rhizosphere-enhancing microorganisms)
Biofor	(forestry and forest products)
Biominet	(mineral leaching and metal recovery)
Bionet	(human and animal health care products)
Bioqual	(waste treatment)

- a federal cost-shared program, which is administered by the National Research Council through the Industrial Research Assistance Program.

Source: Biotechnology Secretariat, Industry, Science and Technology Canada.

capacity. The Science Council of British Columbia and Quebec's Conseil de la science et de la technologie are two such examples.²⁴

In addition to these efforts, several federal science-based laboratories have been strengthening their in-house research competencies and their commercialization linkages with private sector clients. For example, Investment Canada, Industry, Science and Technology Canada, the National Research Council of Canada, and External Affairs and International Trade Canada have been active in promoting Canadian expertise abroad (through investment counsellors, technology development and strategic alliance officers, and science and technology counsellors) with the object of attracting foreign investment in biotechnology ventures as well as opening new markets with our trading partners.²⁵

The Canadian biotechnology community has grown considerably over the past decade and now includes over 200 firms (87 per cent of which have alliances with at least one other organization). Firms such as Allelix, IAF Biochem, Diagnostic Chemicals, and Quadra Logic Technologies have matured from scientific research organizations to competitive technology-based firms. The National Research Council regularly organizes a major industrial biotechnology conference. Participants at the December 1991 conference discussed new advances, identified regulatory and other impediments, and assessed the financial and human resource issues facing the sector. International developments are also explored regularly. Such organizations as the Industrial Biotechnology Association of Canada and the Canadian Institute of Biotechnology benefit

greatly from the contacts made and renewed at the gathering. The Canadian Institute of Biotechnology, established in 1989, is now working with 11 non-profit groups across Canada who act as clearinghouses for information and expertise on biotechnology.

In its 1991 report *Biotechnology in a Global Economy*, the U.S. Office of Technology Assessment encapsulated the strengths and weaknesses of 16 countries in biotechnology. Canada's strengths were identified as a revised patent act, a biotechnology strategy to foster growth, and national networks. Weaknesses were identified as cutbacks in federal funding in support of R&D, limited sources of capital, and few large companies.²⁶ The Canadian biotechnology community is familiar with these and other impediments.

The private sector organizations involved with biotechnology-related products and processes will have to be attentive to shifts in the international marketplace – shifts that will leave them at a distinct disadvantage if they are not well positioned through such instruments as strategic alliances and licensing arrangements. Some of these market shifts concern not only prices, but also the regulatory environment for conducting business.²⁷ Despite all the activity on biotechnology in Canada, there is still concern over whether Canada's biotechnology business has sufficient scale to remain competitive. Behind this concern is the issue of availability of adequately trained personnel. Important questions need to be asked about whether such an industry (which requires extensive capital) can support itself on a global scale.

Among the non-commercial issues associated with this strategic technology are those dealing with ethics. The Science Council alerted the Canadian public to some of these ethical questions with the publication of its report *Genetics in Canadian Health Care*.²⁸ Among the points made by the Council were that genetic services should be initiated only if there are benefits to the recipient such as disease prevention or treatment, or lifestyle or reproductive choices. As well, individuals and families should have access to beneficial technologies in order to make informed decisions about their own health care and reproductive options. A number of related issues have been addressed before the Royal Commission on New Reproductive Technologies. Some witnesses have questioned whether technologies and procedures developed for commercial use with animals should be applied to human beings.²⁹

Public acceptability is another important issue. The European Commission conducted a poll in 1991 on what the public thought about biotechnology. Half the 12 800 people surveyed felt biotechnology would improve life. More than 90 per cent of respondents called for government control in the seven areas of biotechnology research listed, yet only 7 per cent said they trusted public authorities to give accurate information (compared to 1.3 per cent who trusted industry, 23 per cent who trusted environmental organizations, 27 per cent who trusted consumer organizations, and 17 per cent who trusted universities). The attitude to genetic engineering is much the same elsewhere. The public worries about the risks involved in using the results of certain discoveries but tends to approve of specific applications, for example in medicine and agriculture.

The public acceptance issue has yet to be raised substantively by the Canadian public, although the National Biotechnology Strategy, having undergone a comprehensive evaluation during the course of the past year, may deal with it. We can also expect that the evaluation will re-orient the directions and future funding for biotechnology at the federal level.

The Science in Biotechnology

Molecular biology, genetics, chemistry, chemical engineering, plant biology, veterinary science – these are only a few of the scientific fields required to deal with this interdisciplinary subject. Biotechnology research is a major component of seven of the federally funded Networks of Centres of Excellence.

Last year the Royal Society of Canada began a major assessment of Canadian performance in molecular biology (including proposed case studies in human genetics/mammalian development, molecular evolutionary biology, molecular biology in clinical research, protein structure and function, and plant molecular biology). The ultimate objective is to identify and recommend ways to enhance Canadian performance.

At the international level, debate has continued over the future funding of the Human Frontier Science Program (HFSP), a \$20 million effort to enhance international research exchanges and collaboration on the elucidation of brain functions and biological functions through molecular-level approaches. The program, approved at the 1988 Toronto Economic Summit, is open to G-7 researchers as well as Swiss and European Community scientists.

The HFSP funds interdisciplinary, internationally collaborative research through grants, fellowships, and international workshops (see Table 1). Canada is represented on its board of directors as well as on its Council of Scientists, which provides guidance on research directions. Canadian researchers have benefited considerably from this program and Canadian financial input has been limited to paying the costs of a Canadian representative at the secretariat in Strasbourg. It has been estimated that for Canada's \$140 000 investment in the HFSP, approximately \$4 million will accrue to science in Canada in the form of research awards and fellowships. As the program moves into its second phase, it is expected that contributions from member countries, including Canada, will increase.

One of the components of the HFSP is focused particularly on the brain and its functions. Canadian expertise in the neurosciences is noteworthy, and in 1991 Montréal was the site for the annual meeting of the International Brain Research Organization. Modern neuroscience is an intensely vital, multidisciplinary field drawing on the medical sciences and natural sciences such as

physiological psychology, cognitive psychology, neuroendocrinology, nerve regeneration, and invertebrate systems. These are disciplines in which Canada has considerable strength.

At a meeting hosted by Queen's University in March 1991, a number of Canadian researchers interested in the HFSP were invited to discuss Canada's continued involvement in this innovative endeavour and to explore future roles in international scientific research. The meeting raised a host of generic issues surrounding the internationalization of science, national interests in science, and the interplay between national and international institutions promoting collaboration. One pressing issue concerns the financing of Canadian scientists to participate in programs such as the HFSP. Participation imposes a certain discipline on the national scientific infrastructure: how, for example, can it meet new funding and personnel demands without skewing the priorities of the Canadian research community, which must attract and train new scientists in a diverse range of areas of leading-edge research?²⁰

Similar questions could be raised about Canada's role in other international scientific

Table 1. Human Frontier Science Program, Applications and Awards, 1991

Research Grants/Long-Term Fellowships			
	Applications	Awards	Destination of Fellows
	No. of principal applicants	No. of principal applicants	No. of scientists
U.S.	80 / 34	15 / 8	46 / 57
Japan	29 / 71	3 / 24	27 / 3
U.K.	31 / 37	4 / 7	13 / 10
France	23 / 41	2 / 11	13 / 6
Italy	17 / 20	1 / 2	4 / 2
Germany	17 / 29	4 / 11	12 / 4
Canada	16 / 16	2 / 6	3 / 6
CEC	26 / 32	1 / 8	6 / 2
Others	- / 68	- / 13	15 / 2
Totals	239 / 348	32 / 90	139 / 90
Numbers in 1990	235 / 202	30 / 80	

Source: Announcement of Human Frontier Science Program Second Year Award, 19 April 1991.

programs, such as the Human Genome Project, a 15-year program designed to locate and characterize the estimated 100 000 genes of the human genome;³¹ the Superconducting Super Collider, a Texas-based project to build the world's largest, most powerful particle accelerator (Canadian participation is being aggressively sought); and the International Thermonuclear Experimental Reactor, an international fusion demonstration project involving Japanese, Russian, American, European, and Canadian scientists, which is now at the engineering design stage.

The Bleeding Edge of Technology: Containing the Leakage

Science has traditionally been international in scale and scope, and technology is increasingly so. Because of the nature of strategic technologies, and because of the rapid pace of technical change, it is difficult to contain the benefits of R&D within borders. As the Organisation for Economic Co-operation and Development reminds us:

Technological development is...transforming conditions for innovation everywhere. [This] should lead to new approaches to the management of policy, where the focus is all too often exclusively domestic. Mechanisms for closer collaboration in R&D between countries have to be reinforced, and thought should be given to rules of the game to ensure the appropriate diffusion and distribution of knowledge and technologies across countries.³²

The diffusion side of science and technology policy is important in order to obtain the potential benefits from R&D, regardless of the country where the R&D takes place. This suggests that the most effective policy for governments may be to coordinate their research with that of other countries in developing generic technologies, and then to use the policy measures needed to ensure that these technologies are rapidly diffused in their individual countries.

The OECD international conference on technology and the economy held in Montréal early in 1991 was strewn with references to the importance of generic technologies, and to the value of having a well-developed industrial infrastructure that can capture their benefits.³³

Canada's space sector, with its investments in research and technology, is a good example of the application of generic technologies for economic

benefit. The space sector has a strong export capability, thanks in no small part to the development of the Canadian Space Program and the creation of the Canadian Space Agency. The Space Program (which will provide \$3.7 billion to the year 2000) is undergoing major restructuring as the agency develops a long-term plan to strengthen Canadian space science and technology. The plan will assist Canada's space industry in positioning itself for the global competition that will emerge over the next two decades. Indeed, the Space Program serves as a critical "technology driver" in non-space industries as well as the space sector.³⁴

In preparing the plan, the Canadian Space Agency established eight working groups to cover various issues, including earth observation systems, space science, space infrastructure, and international relations. In addition, it held a number of regional consultations with the space community across the country in December 1991 and January 1992. It is expected that the long-term plan will be complete by June 1992. Assuming the federal Cabinet approves the plan, new financial resources will be committed later in the year.

Over the summer of 1991, the rescue from near-collapse of U.S. financing for Space Station Freedom (to which Canada had committed more than \$1 billion – over 30 per cent of Space Program commitments) demonstrated how Canadian industrial, academic, and government communities can work together as effective lobbyists. It also underscored the wisdom of investing in other international technology programs such as those of the European Space Agency, and its earth observation activities.

The year 1992 has been designated International Space Year, but space is a glamorous business at any time. Accordingly, many countries invest in space for international prestige. The announcements by the Quebec and Ontario governments that they will support separate bids by Montréal and Toronto to locate the International Space University in Canada will no doubt provide a good test of federal-provincial-industry and interprovincial relations over the coming months.³⁵ A decision is expected by August 1992. The ISU, established in 1987 to train researchers and promote international research in space exploration, has no fixed campus, and a number of other cities (among them, Turin, Nice, Toulouse, and Houston) have submitted bids to be hosts for a permanent campus. In an encourag-

ing sign for international cooperation, former ISU students (approximately 600 to date) are forming an international association to suggest ways in which the future campus, its satellites, and its curriculum can be developed.

The Necessity of Technological Cooperation

The space sector, like other strategic industrial sectors, must rely for its survival on technology cooperation arrangements between firms. One important motive for expanding these strategic partnerships is the increased complexity and intersectoral nature of new technologies. Although companies seeking strategic alliances do so for a wide range of reasons, access to scientific knowledge or complementary technology is a critical one. A study of cooperative agreements in new materials, biotechnology, and information technologies shows that about 90 per cent of such agreements were forged during the 1980s. In new materials, over 62 per cent were initiated since 1985; in biotechnology and information technologies the comparable figures are approximately 60 per cent and 55 per cent, respectively.³⁶

The question of access to new technologies is fundamental for a small, open economy that generates about 2 per cent of the world's technology.³⁷ For this reason, Canada is a regular participant in multilateral forums dealing with access to technology and intellectual property issues. As well, the lifting of restrictions on selling and exporting certain key industrial technologies (such as computers, telecommunications equipment, and machine tools) to Eastern Europe is a blessing for firms that wish to expand their markets into the region.³⁸

In the more exotic new technologies, Canada is struggling to keep abreast of developments. In areas such as mechatronics, nanotechnology, electronic materials, and silicon-based polymers, researchers are pushing the frontiers of science, technology, and instrumentation.

Another type of "frontier" technology involves systems management and workplace innovation. One example is the Japanese-initiated technology program called Intelligent Manufacturing Systems. IMS was unveiled in 1989 by the Japanese Ministry of International Trade and Industry as a trilateral effort (the United States, Japan, and Europe) to conduct research on a host of advanced manufacturing technologies, including production system development, production-control equipment and processing, application

technology for new materials, and human factors in production. The proposal was for a \$1 billion, 10-year international research program (with Japan funding 60 per cent, the United States 20 per cent, and Europe 20 per cent) in an area of perceived Japanese strength. The Japanese "noblesse oblige" view was that it should diffuse such knowledge to other countries and thus improve its standing in the international S&T community, where "the disparity between its wealth and its technical contributions has engendered resentment."³⁹

The initial Canadian response was muted. First, the Japanese (who are inexperienced at organizing international collaborative structures) had not sought official channels to launch the initiative, having used the Society of Manufacturing Engineers as the conduit into the United States and Europe, as well as Canada. Second, the Japanese had excluded Canada from the early discussions, preferring instead to work out the details with just the United States and Europe. Also, on the Canadian side there was initially no obvious mechanism to ensure dissemination of the results of the research to potential users. Eventually, Industry, Science and Technology Canada established an Industry Advisory Committee to guide industrial involvement in the program. Canada was included after aggressive lobbying of Japan on the part of External Affairs and International Trade Canada (and its science and technology counsellor in Tokyo).

Following these and other efforts, an international steering committee meeting was held in Toronto in early 1992 to elaborate the two-year feasibility study. Canadian firms will eventually have access to what is clearly turning into a global strategic area: management of new production techniques and human resource questions in the adoption of manufacturing technologies. Canadian industry will be involved in the development of the feasibility stage of IMS, and will have an input into research design as the program develops.

Recognizing Excellence

If the international technology game is a difficult one for Canadian organizations to master, international science appears, on the surface, to be a better ballgame. After all, as a small country, Canada (and others in the same category) contributes proportionately more than its share to world science.⁴⁰

This is not only because science is often cheaper to perform than technology, but also because Canada still retains its strengths in those areas essential to building a nation: sciences related to natural resources, medicine, and engineering.⁴¹ The institutional system supporting this basic research has been built up over decades. But an active debate is now emerging in Canada on how to maintain a balance between research at the international level and research tied directly to industrial needs. This debate partly manifests itself in the rhetoric of policy makers who often fail to distinguish between science and technology as separate but linked activities. The Canadian S&T system suffers from a number of difficulties because of this (discussed further in the chapter on infrastructures).

Science needs its own rewards. As the Minister for Industry, Science and Technology, Michael Wilson, notes:

the young scientist just out of university is angry and frustrated that he (she) cannot find a job. Like thousands of our young people, he (she) is talented and worked hard. But with only 4 manufacturing firms out of 100 doing any research and development, his (her) hard work may not find the outlet it deserves.⁴²

Like any nation bent on redressing its former lack of recognition of creative and entrepreneurial contributions to society, Canada has developed a host of reward structures. These range from the Mercure Awards in Quebec (which recognize outstanding achievement in science and technology), to S&T leadership awards in Alberta and Newfoundland, to the national Manning Awards (established in 1981 in honour of former Alberta Premier and Senator Ernest Manning). To enhance the career development of outstanding and highly promising scientists and engineers, NSERC annually awards the E.W.R. Steacie Fellowships. The 1991-92 fellowships went to Nick Kaiser at the University of Toronto, a leading expert in physical cosmology; Ram Murty at McGill University, one of the world's experts on modular forms and L-series in arithmetic analytic algebraic geometry; Indira V. Samarasekara of the University of British Columbia, for her work in continuous casting and hot rolling of steel and gallium arsenide crystal growth; and Leslie Smith at the University of British Columbia, for his contributions in the science of hydrogeology. For sustained and outstanding contributions to Canadian research in the natural sciences and

engineering, NSERC also awards the Canada Gold Medal for Science and Engineering. Raymond Lemieux of the University of Alberta, one of Canada's leading experts on carbohydrate chemistry and founder of several science-based companies, was honoured in 1991.

Canadian scientists are also recognized internationally. In 1991, for example, the first Stockholm Water Prize, a U.S. \$150 000 international environmental award made in recognition of an outstanding contribution in the field of water conservation, went to David Schindler of the University of Alberta for his work on eutrophication and acidification, research that has led to improvements in environmental legislation in Canada, the United States, and the European Community.

Rewarding excellence should not be restricted to the academics. Rewards for entrepreneurs, technicians, teachers, and others who contribute to national excellence are also required. In many cases such recognition is given, but the fact remains that Canadian society does not place as high a value on excellence as other countries do.

Big Science, Small Country

In the summer of 1991 the Science Council asked the readers of its newsletter, *In Touch*, for their views on, among other things, the importance of frontier science and technology. Responses indicated a sharp division over Canadian participation in international "big science." Some readers were concerned that "we risk being left behind and dependent on other countries." Others argued that we should "balance political lobbying (e.g., KAON, Space Station) against Canada's real needs."

The conundrum is a difficult one for a country committed to keeping its science at the forefront of world advances. It is equally problematic for the scientific community, which is hearing government exhortations that research should be "going global" when funding levels for basic research are eroding.⁴³ And, finally, there are major global problems that can be addressed only by large-scale, interdisciplinary scientific and medical collaboration at an international level (these include global climate change, environmental pollution in circumpolar regions, and AIDS research).

As indicated earlier, the issue concerns the relationship between an active scientific community and those people who have been elected to make

decisions on how public funds should be invested. Science wants to control its own agenda. Government wants to specify priorities. Industry seeks relevance. The resolution of this contest is made no easier by the current restraints on public funding.

In Canada, the debate on participation in "big science" projects is muted; it is typically confined to the corridors of power, and is an issue that even the scientific community itself has rarely debated openly. In contrast, a hot and pluralistic debate on this subject is evident at all levels in the United States and, increasingly, in Europe and Japan. In the American scientific community the argument over the pros and cons of big versus little science has raged for several years. Unfortunately, some of this debate tends to gloss over the changing nature of the research practice (e.g., the tendency toward larger-scale, multidisciplinary projects and sophisticated and costly instrumentation).

The issue now surfacing in most countries faced with participating in international projects is: to what extent will it mean less funding for undirected research or little science by individuals? Many see a real threat that the latter could go the way of the dodo. In the United States, such pessimism is reinforced by an analysis showing that megaprojects account for fully one-third of total requests for civilian research funding in the U.S. fiscal 1991 budget.⁴⁴

The OECD's response to the issue of cooperation in big science was contained in a communiqué from a ministerial meeting in March 1992. It argued for a systematic exchange of views and information among member countries on megascience projects and large-scale programs before they are launched by national authorities.

Canada participates in this debate, as we must, but our capacity to respond to foreign calls on our resources is limited, especially considering that Canadian scientists are already involved in such projects as Space Station Freedom, the European Organization for Nuclear Research (CERN), the Ocean Drilling Program, the Global Change Program, the Human Genome Project, and the International Thermonuclear Experimental Reactor, and Canada is considering participation in the Superconducting Super Collider. Moreover, the Canadian scientific community has not clearly demonstrated its ability to respond coherently, thus leaving some doubt as to whether Canada will, in future, be seen as a reliable partner in

international scientific ventures of this sort. Some question whether Canadian expenditures should, in any event, mirror those of larger countries.

The Queen Elizabeth Telescope, the High Altitude Research Project, the Canadian Long-Base Array, Lithoprobe, the Sudbury Neutrino Observatory, the Gemini Telescopes, and now KAON, represent a lineage of big science projects that have tested the scientific community's resolve over the past several decades.⁴⁵

A Four-Letter Word: KAON in Context

Decisions on KAON and other big science investments involve much more than scientific egos. They can affect the future course of scientific disciplines and, at least from the decision-making perspective, whether science itself is perceived as an investment in a nation's infrastructure. Big science investments can also benefit a country's industrial base.

The KAON case is a classic example of how big science – properly packaged and championed – can have some measure of success in a small country like Canada, even though there remains some doubt whether the project will provide significant contributions to physics or whether it will deliver its promised economic returns.

KAON is an outgrowth of the Tri-University Meson Facility funded by the National Research Council and managed by four Canadian universities. TRIUMF is a national particle physics laboratory that houses a particle accelerator. The idea is to upgrade this facility into a faster accelerator that will boost the energy of TRIUMF's beams by 60 times, allowing the creation of new short-lived particles called kaons. By producing these particles, the new instrument will give scientists unique tools to understand atoms, stars, and the very nature of our universe.

The triumph of KAON has as much to do with selling science (as a commodity) as it has to do with advancing the frontiers of knowledge. As the promotional literature for the project notes, "in jobs alone, 17 000 person years of employment will be created during construction, with another 2800 per year when the project is operational."

After numerous feasibility studies and evaluations, as well as advice from a large portion of Canada's scientific community and policy advisory apparatus (who in general did not view the proposal favourably), the KAON issue came to a head in September 1991 when the federal govern-

ment offered to commit \$236 million (about one-third of the estimated construction costs) to KAON.

The commitment, to begin in fiscal year 1995-96, also included a negotiable amount for operating costs when the facility comes on line (expected in 1998). The KAON proponents and the British Columbia government (if it accepts the federal offer) now have the task of seeking the projected \$200 million in international commitments, as well as ensuring that cost overruns do not inflate the provincial commitment.

The British Columbia government, and the parts of the physics community who have been promoting this \$1.2 billion investment, have played their cards well. The fact that KAON was sold as a key to assisting the B.C. economy went down well with the governing and opposition parties alike in the midst of an election year. In addition, the KAON proponents were careful to enlist some of the country's highest-profile professional lobbyists to make their case to the federal government. Among the arguments the pro-KAON lobbyists used were:

National unity: The argument was made that by investing in KAON, the federal government would improve morale within the B.C. science and technology community – a community that has been neglected by federal S&T and infrastructure investments in the past and that now could contribute to national prosperity more effectively. KAON is designed as an international facility, and will lend support to the building process for the National Science and Technology Policy led by the Council of Science and Technology Ministers (described in the chapter on infrastructures).

International relations: The entrepreneurial drive of the KAON proponents led them abroad to drum up promises of financial support from prospective foreign partners to the tune of \$200 million. This international effort not only resulted in the usual support from the subatomic communities of other countries, but also took on an unprecedented air when the White House chief science adviser (a Canadian-educated physicist who knows the science community well) made at least one personal lobbying appearance before selected federal Cabinet ministers. Further, the implied argument was that a G-7 nation such as Canada could not afford *not* to have a mega-science facility and continue to participate in large-scale projects located elsewhere.

Links to industrial competitiveness: The project's proponents sold KAON as an important step in

advancing the state of subatomic physics, but they also made direct links to the competitiveness agenda, arguing that the spin-offs from KAON "may allow us to discover...dramatic new treatments for cancer" and that KAON "has the potential to assist Canadians in developing dozens of new commercial enterprises." Emphasis on the local economic impetus afforded by building an international facility made opposition difficult for the B.C. economic development and industrial communities.

Supply of skilled human resources: The proponents played on the notion that the scientific community in Canada is frustrated with the lack of national vision in support of basic science, especially the poor signals being sent to prospective students about the value of science as a profession in this country.

Big versus little science: This was a relatively easy argument to put forward within the subatomic physics community. But it was much more difficult (and still is) to convince others that funding KAON would not have an overall negative impact on funding levels for the science community at large. For example, the difficulties associated with obtaining \$2 million from federal coffers to match Quebec's contribution to the operation of the national Tokamak fusion reactor in 1991 were seen as a sign of trouble ahead. The little science concern was alleviated in part by the subsequent announcement that the federal government would be increasing the base funding levels for the research granting councils.

Contributing to the jigsaw puzzle of science: The proponents sold KAON as complementary to other big physics projects, arguing that it was neither redundant nor a threat to the national investments of other countries.⁴⁶

Whether one is pro or con, the KAON issue demonstrates that the outmoded linear model of innovation (which holds that basic research begets applied technology which begets development which begets commercial application) is alive and well in Canada.⁴⁷

Assuming that KAON goes ahead, it will be interesting to track both its domestic impact and its effect on our international scientific image. Just as crucial will be the extent to which this high-profile exercise in big science lobbying has affected the harmony within the scientific community. George Brown, the U.S. House Science and Space Committee chairman, sounded an alarm when he noted that scientists who are unable to get together and define their own priorities are nothing

but a headache in Washington, especially when their perennial anxiety over tight budgets leads them to backbiting, badmouthing, and individual lobbying.⁴⁸ Meanwhile, there are lessons in the KAON saga for Canada's scientific community. First, know your market, and learn how to sell. Second, learn how to set priorities.

This second lesson is a critical one. As the authors of the Bahcall report on U.S. astronomy and astrophysics warn, "astronomers have recognized that if they do not set their own priorities, then funding agencies and congressional officials will do it for them."⁴⁹ In Canada, with a three-year spending cap on research to take effect this year, it will be all the more important for choices to be made. The scientific and technical communities must sort out priorities for their own disciplines, yet this alone will not be sufficient because the more difficult issue is examining the research envelope across disciplines. Ultimately, the key question is: "How much science is enough?" The S&T communities must also adopt a more sophisticated approach to get their messages across to politicians. The students of astronomy and astrophysics have cautioned:

If our country does not live up to the status to which it aspires, ours may be a future of denial; industries denied the necessary support expertise in innovative technologies arising from unexpected sources; firms denied the chance to participate and compete in the expanding global markets created by such technologies; students denied skilled and motivated teachers; and people denied a sense of Canadian involvement and perspective in the exciting discoveries being made around them.⁵⁰

Conclusion

This section has traced some of the developments in Canada's thinking about strategic technologies and new scientific frontiers. A considerable national discussion can be had concerning the value of adopting and creating new technologies. In fact, many have argued that Canadians should be the fastest and smartest users of new technology, but not necessarily the inventors and developers of it. Quite often, however, this ignores the fact that a sound base in cutting-edge research is required in order to decide on what science and technology is to be adopted.

The public discourse over the past year or so has given signals that it is becoming more open, and is a sign of the democratic nature of science policy development in Canada. The debate needs to continue if only to provide Canadians with the best possible information and insights on how advances in science and technology will affect their quality of life and that of future generations.

Notes

1. Kenneth Prewitt, "The Public and Science Policy," *Science, Technology and Human Values* 7 (Spring 1982): 13.
2. For a good discussion of the technology policy issues in the United States, see L.M. Branscomb, *America's Emerging Technology Policy*, Discussion Paper 91-12 (Cambridge, MA: Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 1991).
3. This is clear from the 1991 *White Paper on Science and Technology (Summary): Development of Globalization of Scientific and Technological Activities and Issues Japan Is Encountering* (Tokyo: Science and Technology Agency), 1991.
4. For a discussion of nanotechnology, see P.A. Hansson, "Nanotechnology: Prospects and Policies," *Futures* (October 1991): 849-859. Also, see special section of *Science*, "Engineering a Small World: From Atomic Manipulation to Microfabrication" (29 November 1991): 1300-1311.
5. In 1971, a well-known American political scientist made the following prescient remarks about the Canadian science policy scene: "Canadian science policy cannot be isolated from the two fundamental political issues facing contemporary Canada. The first is the increasing integration of the Canadian and American economies.... The second is the constitutional crisis generated by the rise of French-Canadian nationalism." Robert Gilpin, "Science Policy for What: The Uniqueness of the Canadian Situation," paper for discussion at the Conference on Science Policy and Political Science, Science Council of Canada, Ottawa, 18-19 March 1971.
6. For a brief description of these and other unique technology centres, see *Technology Networking Guide: Canada*, draft report (Ottawa: Industry, Science and Technology Canada, Technology Liaison Directorate, September 1990).
7. Some of the more recent material includes: National Advisory Board on Science and Technology, *Innovation and Canada's Future Prosperity* (Ottawa, 1991); M.E. Porter and the Monitor Company, *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Business Council on National Issues and Minister of Supply and Services, 1991); and A.M. Rugman and J.R. D'Cruz, *Fast Forward: Improving Canada's International Competitiveness* (Toronto: Kodak Canada, Inc., 1991).

8. See, for example, Ontario Premier's Council, *Competing in the New Global Economy*, vol. 2; Science Council of British Columbia, *Strategic Planning for Applied Research and Knowledge*, 1988; and Quebec's recent work on industrial sectors as indicated by "Our Economy: State of Emergency," speech by Minister of Industry, Commerce and Technology, Gérald Tremblay, to the Convention of the Professional Corporation of Industrial Relations Counsellors of Quebec, Montréal, 10 September 1991.
9. Emerging research areas, like strategic alliances, are misnamed. The latter, if they are strategic to a corporation, are not public (once public, they cease to be strategic). The former are not emerging at all since research on most broadly defined emerging sciences or technologies is usually in full gear with large-scale programs in place worldwide. As one commentator has wryly noted, "it takes neither predictive powers nor special talents for science policy to identify these areas."
10. See U.S. Department of Commerce, *Emerging Technologies: A Survey of Technical and Economic Opportunities*, Spring 1990; Office of Science and Technology Policy, *National Critical Technologies*, 1991; and Council on Competitiveness, *Gaining New Ground: Technology Priorities for America's Future*, 1991.
11. For a sampling of some of this work, see the "Country Profiles" section of the 1991 *Science and Technology Policy Outlook*, Organisation for Economic Co-operation and Development, forthcoming.
12. Special emphasis, however, will be placed on biotechnology and environmental technology. See NRC *Long-Range Plan 1990-1995: The Competitive Edge* (Ottawa: National Research Council, 1991).
13. F. Narin, "Indicators of National and Company Technological Strength (Using Patent Citations)," paper presented at a Science Council of Canada seminar, Ottawa, 14 November 1991.
14. See Science Council of Canada, *Harnessing Science and Technology for Cold Regions* (Ottawa: Ministry of Supply and Services, 1989).
15. The Polar Commission was first proposed in 1987 in E.F. Roots et al., *Canada and Polar Science* (Ottawa: Department of Indian and Northern Affairs, 1987) and again in 1988 by T.H.B. Symons, *The Shield of Achilles: The Report of the Canadian Polar Research Commission Study* (Ottawa: Department of Indian Affairs and Northern Development, 1988). Recommendations as to its mandate were suggested in the Science Council of Canada's April 1991 report, *Northern Science for Northern Society: Building Economic Self-Reliance* (Ottawa: Minister of Supply and Services, 1991).
16. See Keith Newton, "A Dual Approach to Technology Policy," in J. Brothie et al. (eds.), *Cities of the 21st Century* (Melbourne: Longman Cheshire, 1991), 353-363.
17. "What Drives the Engines of Innovation?" *New Scientist* (16 November 1991): 35-40.
18. Guy Steed and Scott Tiffin, *A National Consultation on Emerging Technology*, discussion paper (Ottawa: Science Council of Canada, May 1986).
19. Government of Alberta, *Toward 2000 Together Initiative* (Edmonton, 1991).
20. Congress of the United States, Office of Technology Assessment, *Biotechnology in a Global Economy* (Washington, D.C.: U.S. Government Printing Office, October 1991), 3.
21. R.A. Russel, "What is Human? Sci-Tech in 2016," in *Science for the Future: 1990-2016*, background analysis and report to the Science Council of Canada, Vector Public Education Inc., Ottawa, 1990 (unpublished).
22. See for example, Cabinet Office Advisory Council on Science and Technology, *Developments in Biotechnology* (London: Her Majesty's Stationery Office, 1990); and Commission of the European Communities, *Promoting the Competitive Environment for the Industrial Activities Based on Biotechnology within the Community*, Commission communication to Parliament and the Council (Brussels, 19 April 1991).
23. National Biotechnology Advisory Committee, *Fourth Report, 1989-90*, 1990. The federal government also has advisory committees in a number of other strategic technologies, including the National Advisory Panel on Advanced Industrial Materials and the National Advisory Board on Pharmaceutical Research.
24. See Biotechnology Planning Report for the Science Council of British Columbia, *SPARK* (Vancouver, January 1988); and Conseil de la science et de la technologie, *Le développement industriel des biotechnologies au Québec* (Québec, 1985).
25. See, for example, Investment Canada, *Biotechnology: Canadian Partners for Global Markets* (Ottawa, 1991); and External Affairs and International Trade Canada, *Biotechnology: The Canadian Experience* (Ottawa, 1990).
26. Congress of the United States, Office of Technology Assessment, *Biotechnology in a Global Economy* (Washington, D.C.: U.S. Government Printing Office, October 1991), 231-232.
27. On some of the regulatory issues affecting industry, see the 1991 report by the President's Council on Competitiveness, *Report on National Biotechnology Policy* (Washington, D.C., February 1991).
28. Science Council of Canada, *Genetics in Canadian Health Care*, Report 42 (Ottawa: Minister of Supply and Services, 1991).
29. Royal Commission on New Reproductive Technologies, *What We Heard: Issues and Questions Raised during the Public Hearings* (Ottawa, September 1991). The final report of the commission is expected in 1992.
30. Queen's University, *Workshop on Canada's Participation in the HFSP and Our Future Role in International Scientific Research* (Kingston, March 1991).
31. For a discussion of some of the ethical issues raised by the Human Genome Project, see A.C. Stewart, "Ethical and Social Implications of the Human Genome Project: The Issues in the U.K.," *Science and Public Policy* (April 1991): 123-129.
32. Jean-Eric Aubert, "What Evolution for Science and Technology Policies?" *OECD Observer* (February/March 1992): 5.
33. *Technology and the Global Economy: An International Policy Conference, Summary of Discussions* (Paris: Organisation for Economic Co-operation and Development, Technology-Economy Programme, 1991).

34. Canadian Space Agency, *Background Paper on the Canadian Space Program* (Montréal, November 1991).
35. See Ontario Ministry of Industry, Trade and Technology, "Minister announces Ontario's support for International Space University bid" (Toronto, 30 September 1991); and Montréal: *A Unique Opportunity - Une Occasion à saisir*, 1991.
36. Luc Soete, "The internationalisation of science and technology (policy): how do nations cope?" Maastricht Economic Research Institute on Innovation and Technology, January 1991.
37. The 2 per cent figure (a number often used but rarely explained) is derived from the annual percentage of patent applications filed in the United States by Canadian residents (in 1988, the actual figure was 1.9 per cent). Obviously, this is only a partial measure of technology activity in Canada; it should therefore be used with other measures of Canada's contribution to the world technology pool.
38. See John R. de la Mothe and Paul Dufour, "The New Geopolitics of Science and Technology," *Technology in Society* 13 (1991): 179-187.
39. George R. Heaton, Jr., *International R&D Cooperation: Lessons from the Intelligent Manufacturing Systems Proposal*, Discussion Paper No. 2 (Washington, D.C.: The Manufacturing Forum, 1991).
40. See Vivien Walsh, "Technology, Competitiveness and the Special Problems of Small Countries," *STI Review* 2 (September 1987): 81-133.
41. One explanation for why certain basic sciences originally developed in former colonies such as Canada has to do with imperial intentions. To extract the natural resources of the colony, it was necessary to develop geological, agricultural, fisheries, and forestry sciences. In addition, a healthy colony required good medical facilities and health care. The need for sound transportation and other infrastructure brought about the development of engineering.
42. Speech by the Honourable Michael Wilson on the tabling of a discussion paper, *Prosperity through Competitiveness*, 29 October 1991.
43. The National Research Council dealt with this issue in its long-range plan by noting that it "will limit its role in the planning, building, managing, and funding of new national and international science facilities external to NRC (outside of astronomy or other mandated responsibilities) to initiatives in which NRC has been requested or instructed by the Government of Canada to play a significant role, and for which adequate financing has been assigned" (our emphasis). *NRC Long-Range Plan 1990-1995: The Competitive Edge* (Ottawa: National Research Council, 1991), 21.
44. Genevieve J. Knezo, *Science Megaprojects: Status and Funding February 1991* (Washington, D.C.: Congressional Research Service, Report for Congress, 12 March 1991). Megaprojects include the Superconducting Super Collider, Space Station Freedom, Magnetic Fusion Energy, Moon and Mars Initiative, Earth Observing System, Human Genome Project, HIV/AIDS research, high-performance computing, and Global Change Research program.
45. The Sudbury Neutrino Observatory will use 1000 tonnes of heavy water in a cavern of INCO's Creighton Mine to detect elusive particles emitted from the centre of the sun and exploding stars. Funding - from Canada, the United Kingdom, and the United States - totals \$70 million. The Gemini Telescope project is a proposal by the astronomy communities in Canada, the United States, and the United Kingdom to construct a pair of eight-metre telescopes in Hawaii and Chile. Initially, the Canadian share for this \$240 million project was to have been 25 per cent, but financial constraints have whittled this down to 15 per cent (NRC and NSERC have agreed to share the costs).
46. One should qualify this statement by noting that even within the subatomic physics community in Canada, support for KAON is not unanimous, with some arguing that Canada would be better off spending the money in the Centre européen pour la recherche nucléaire (CERN), and others arguing that scientists in Canada would benefit more from a contribution to the U.S. Superconducting Super Collider.
47. For an innovative approach to the technological innovation model, see J. Ziman, "A neural net model of innovation," *Science and Public Policy* 18(1) (1991): 65-75; and N. Rosenberg, "Critical Issues in Science and Technology Policy Research," paper presented at NISTEP Second International Conference on Science and Technology Policy Research - What Should be Done? What Can be Done?, organized by National Institute of Science and Technology Policy, Kanagawa, Japan, 24-26 January 1991.
48. "Astronomers Forge a Consensus for the 1990s," *Science* (22 March 1991): 1430.
49. J.N. Bahcall, "Prioritizing Science Initiatives," *Science* (22 March 1991): 1412.
50. "Canada Is Opting Out of Frontier Research," article signed by Jamie Mathews and 92 other young astronomers and graduate students at 10 universities across North America, *The Gazette*, Montréal, 5 August 1991.

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